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SONAR TRANSDUCER RELIABILITY IMPROVEMENT PROGRAM (STRIP) FY 81.(U)
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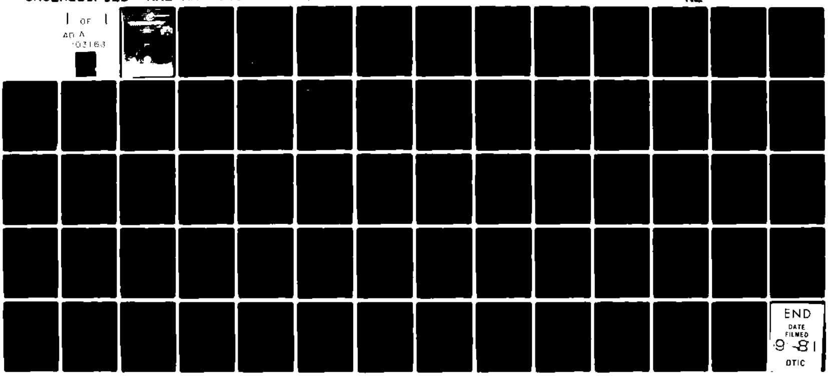

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Cables	Water permeation	Metal matrix composites	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During the third quarter of FY81, efforts in the various tasks of STRIP have resulted in progress toward the program goals as summarized below:

- The voltage at which corona forms about electrodes and hook-up wires in a transducer configuration has been quantified in the laboratory and verified in an actual transducer design.
- An investigation of the effects of using unshielded electrical cable exterior to the submarine hull on the performance and

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reliability of hydrophones has been initiated.

- The DT-605 hydrophones undergoing accelerated life testing have begun to show deterioration of performance after four-years equivalent. Additional years equivalent of CUALT on the TR-316 projectors have revealed that large air bubbles of 2 to 4 cm in size are formed in the other beam sections of the transducers. At present, the air bubbles have not affected the acoustic performance to be out of specification.

- A new phenomenon of increased water permeation through Neoprene-G after 100 days was verified. Furthermore, a second change (increase) in rate was observed at 191 days.

- A parameter variation study on a computer model of a 33-mode stacked ceramic resonator explains the resonance shifting previously observed on the TR-316 transducers. Initial results from an infrared temperature measurement system for obtaining the surface temperature profiles of acoustic resonators under drive are presented.

CONTENTS

SONAR TRANSDUCER RELIABILITY IMPROVEMENT PROGRAM

FY81 THIRD QUARTER PROGRESS REPORT

1. INTRODUCTION

1.1. PROGRAM OVERVIEW

The general objective of this program is to perform relevant engineering development which addresses the operational requirements for fleet transducers for active sonar, passive sonar, surveillance, counter-measures and deception devices, navigation, and acoustic communications. The approach is to develop, test, and evaluate improved transducer design, materials, components, and piece-parts that will meet specified requirements in the operational environment during the entire useful life of the transducer. Standards will be prepared to ensure that results obtained during preliminary testing will be obtained consistently in production. This program should result in improved performance and reliability and reduced costs through better utilization and a more comprehensive characterization of materials and design data.

The Sonar Transducer Reliability Improvement Program (STRIP) is a part of Program Element 64503N. Major task areas with specific objectives to achieve the program goals have been described in the Program Plan and include:

- Task Area A - Encapsulation Methods
- Task Area B - High-Voltage Engineering
- Task Area C - Cables and Connectors
- Task Area D - Transducer Material Standards
- Task Area E - Environmental Test Methods
- Task Area F - Transducer Tests and Evaluation

The FY81 Program Plan for STRIP has been funded at the 1017K level. The specific tasks and their principal investigators for FY81 are listed below:

TASKS		PRINCIPAL INVESTIGATORS	
A	Encapsulation Methods	NRL-USRD	C.M. Thompson
B	High-Voltage Engineering	NRL-USRD	L.P. Browder
C-1	Cables and Connectors	EB/GD	R.F. Haworth
C-2	Cable Shielding	Georgia Tech.	H.W. Denny
C-3	Standard for O-Ring Installation	APL/University of Washington	C.J. Sandwith
D-1	Alternative Materials: Plastics	NWSC	K. Niemiller
D-2	Pressure Release Materials	NUSC	C.L. LeBlanc
D-3	Specification of Elastomers	NRL-USRD	C.M. Thompson
D-4	Transducer Ceramics	NRL-USRD	A.C. Tims

TIMME

E-1	CUALT	NOSC	J. Wong
E-2	ALT Verification	NWSC	D.J. Steele
F-1	Failure Modes due to Water	TRI	P.E. Cassidy
F-2	Ceramic Stack Joints	NOSC	C.I. Bohman
F-3	Reliability & Life Prediction Specification	TRI	R.L. Smith
F-4	TR-122 FMA & Improvements	NRL-USRD	E.W. Thomas
F-5	Metal Matrix Composites	Honeywell	O.L. Akervold
F-6	Improved Hydrophone Analysis	NWSC	M.P. Canty
F-7	Engineering Documentation	NRL-USRD	R.W. Timme

1.2. SUMMARY OF PROGRESS

During the third quarter of FY81, efforts in the various tasks of STRIP have resulted in progress toward the program goals as summarized below:

- The voltage at which corona forms about electrodes and hook-up wires in a transducer configuration has been quantified in the laboratory and verified in an actual transducer design. See Section 3.

- An investigation of the effects of using unshielded electrical cable exterior to the submarine hull on the performance and reliability of hydrophones has been initiated. See Section 5.

- The DT-605 hydrophones undergoing accelerated life testing have begun to show deterioration of performance after four-years equivalent. Additional years equivalent of CUALT on the TR-316 projectors have revealed that large air bubbles of 2 to 4 cm in size are formed in the other beam sections of the transducers. At present, the air bubbles have not affected the acoustic performance to be out of specification. See Section 9.

- A new phenomenon of increased water permeation through Neoprene-G after 100 days was verified. Furthermore, a second change (increase) in rate was observed at 191 days. See Section 11.

- A parameter variation study on a computer model of a 33-mode stacked ceramic resonator explains the resonance shifting previously observed on the TR-316 transducers. Initial results from an infrared temperature measurement system for obtaining the surface temperature profiles of acoustic resonators under drive are presented. See Section 12.

1.3. PLANS

The Program Plan for the FY82 STRIP has been submitted to, and is currently being reviewed by, Naval Sea Systems Command Code 63X5.

1.4. REPORT ORGANIZATION

The remaining sections of this quarterly report will discuss the objectives, progress, and plans for the specific tasks included in the STRIP.

2. TASK A - ENCAPSULATION METHODS

C.M. Thompson - NRL-USRD

2.1. BACKGROUND

A material to be used for filling a sonar transducer must meet a wide variety of specifications. The requirements imposed by the electrical nature of the device include high resistivity, high dielectric constant, as well as resistance to corona and arc discharges. The water environment of the transducer necessitates low water solubility and other attractive solution properties. In addition, the fluid must maintain its electrical and other properties in the presence of any water which permeates the covering. The acoustic requirements are a close acoustic impedance match with seawater and resistance to cavitation at high drive levels. Other obvious properties include compatibility with other components, stability to degradation, and suitable surface tension and viscosity.

With such a wide variety of requirements, it is not surprising that compromises have to be made. The most commonly used fluid for many years has been castor oil. This use in is spite of its high viscosity. Each of the fluids proposed, so far, as a replacement has serious drawbacks. Silicone oils tend to creep onto and wet all of the surfaces of the transducer. This greatly complicates bonding the components together. Polyalkylene glycol (PAG) has the disadvantages of high water solubility and low electrical resistivity. The various hydrocarbon liquids have too low an acoustic impedance and are frequently incompatible with the various plastics and rubbers in the transducer. Further research is necessary to find and qualify fill-fluids which represent the best match to all the requirements imposed upon it.

Transducer encapsulants have long presented a source of transducer failure. The necessity that the encapsulants be resistant to water, have a sufficiently long pot-life for degassing, bond well to the other components, and have high strength has proved to present a very difficult problem. Many other requirements also apply in special cases. The best choice for a polyurethane encapsulant to date has been a toluene diisocyanate (TDI)-polytetramethylene glycol (PTMG) prepolymer which is chain extended with a 4,4'-methylene-bisorthochloroaniline (MOCA). This encapsulant has a long pot-life, good strength, and good water resistance. However, there is serious concern for the health hazards of both the MOCA and the TDI residue in the prepolymers.

2.2. OBJECTIVES

The objectives of this task are:

- To evaluate alternative transducer fill-fluids including fluids specifically for use in towed arrays and to produce specifications for those fluids found suitable.

- To define the relevant properties of encapsulants important in transducer operation, and to develop a non-hazardous replacement for currently used materials.

2.3. PROGRESS

2.3.1. The solicitation for a non-proprietary polyurethane encapsulant was published during this reporting period. Proposals are expected to be received early next quarter. The Source Selection and Evaluation Board will meet soon thereafter and contract award should take place in the middle of the next quarter. It is believed that a significant amount of proposed work can still be accomplished this fiscal year in spite of the unexpected delay in contract award.

The task statement of this solicitation is as follows: Develop a polyurethane encapsulant with the following properties:

- The fomulation shall be nonproprietary, i.e., all components shall have a specified chemical description.
- The propolymer and chain extender shall not be carcinogenic and shall be sufficiently free of hazard that they may be handled with only rubber gloves and aprons as protection. (A prepolymer based on TDI may be acceptable if that prepolymer contains a low level of free TDI.)
- The formulation shall have a degradation of less than 25% in Young's or shear modulus and 90% in volume electrical resistivity after a two-year equivalent immersion in water.
- The formulation shall have a pot-life longer than 30 minutes at 22°C.
- The formulation shall have a mix viscosity of 200 P or less at 25°C.
- The formulation shall adhere to mild steel to the extent that when a test is performed in accordance with ASTM Method D429-73 the failure is cohesive rather than adhesive. The test steel surface may be primed.
- The formulation shall have a tensile strength of greater than 14 MPa.
- The formulation shall have a water vapor permeation constant at 25°C of less than 10^{-7} g cm/cm^2-hr-torr.
- The formulation shall have a density-sound speed product within 10% of 1.6×10^6 kg/m^2 sec.
- The formulation shall be sufficiently transparent to visible light as to allow inspection of components.
- The formulation shall have a Shore A hardness between 45 and 80.

- The formulation shall have a cure cycle of 45 to 90 minutes to gel and 8 hours to full cure at a temperature between 25 and 90°C.

- The formulation shall have a volume electrical resistivity of greater than 10^{12} ohm-cm.

- The formulation shall have a dielectrical strength greater than 300 kV/cm.

- The formulation shall have a glass transition temperature below -30°C.

- The formulation shall have an acoustic attenuation less than 1 dB/cm between 1 and 50 kHz.

- The formulation shall have a cost below $11.00 per kg.

- The formulation shall have a degradation of less than 10% in Young's or shear modulus after a two-year equivalent immersion in castor oil.

2.3.2. The acoustic fluids developed under the NRL-funded 6.1 research program have shown some promise. As reported in the FY81 Second Quarter STRIP Progress Report, these materials show low water solubility limits. Initial studies on the butyl-capped PAG (di-butyl polypropylene oxide) showed it to have a surprisingly low density and sound speed (Figs. 2.1 and 2.2). Consideration of this compound led to the second iteration, a methyl-butyl-capped polypropylene oxide.

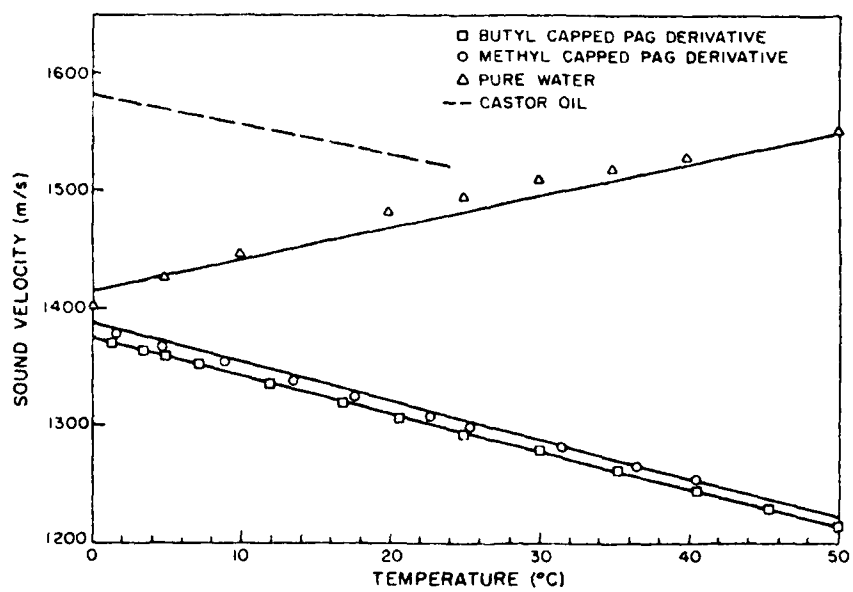

Fig. 2.1 - Sound speed as a function of temperature

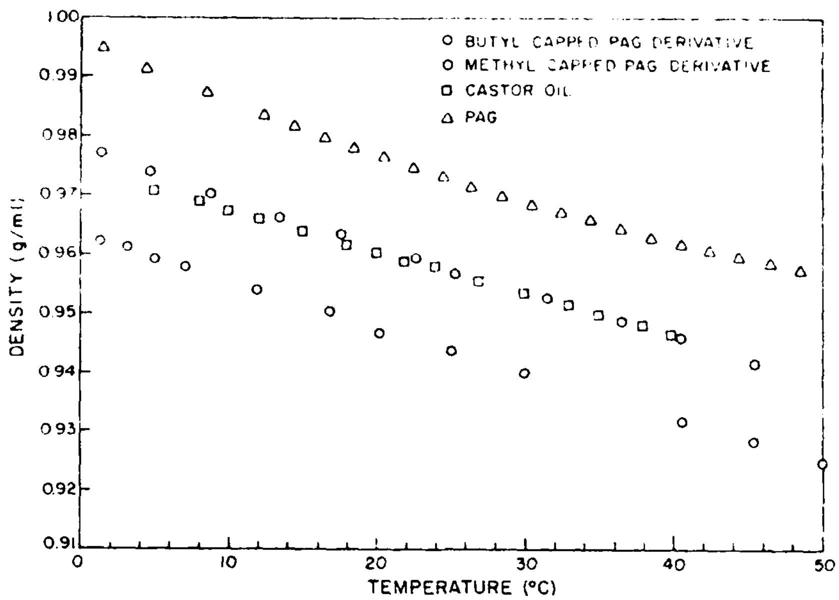

Fig. 2.2 - Density as a function of temperature

This compound, as expected, shows higher densities and sound speeds (Figs. 2.1 and 2.2). The next step is obviously to prepare the di-methyl polypropylene oxide. This synthesis is now underway. If this compound still has too low a density and sound speed, the next attempt will be to prepare a fluorinated-alkyl capped PAG. Viscosity curves for the compounds prepared to date are given in Fig. 2.3. The viscosity of castor oil is not shown because its value is so much higher that it is out of the scale of Fig. 2.3.

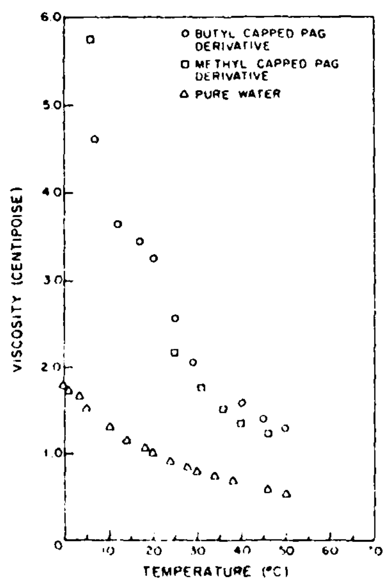

Fig. 2.3 - Viscosity as a function of temperature

2.4. PLANS

- Award contract on polyurethane encapsulants (15 Aug 1981).
- Continue testing on modified polyether acoustic fluids.
- Publish a report on water permeation in sonar transducers and the effect this has on operation and lifetime (cooperative between Tasks A-1 and F-1).
- Prepare and publish a report on transducer fluid properties with a detailed discussion of fluid selection criteria (4th quarter FY81).

3. TASK B-1 - CORONA ABATEMENT

L.P. [illegible] - NRL-USRD

3.1. BACKGROUND

A significant percentage of transducer failures is due to voltage breakdown of insulating materials developing from corona erosion mechanisms. It is not practical to test the completed transducer to measure the effects of corona erosion on lifetime and reliability. To establish reliability factors and quantify protection requirements, corona must be studied as a failure mechanism at the component or piece-part level. Transducer reliability improvement may then be achieved by control of design parameters and construction processes.

3.2. OBJECTIVES

The objectives of this task for FY81 are:

- Study tests, specifications, and procedures that may be used to select coating materials suitable for corona reduction.

- Test various corona reduction coating materials on PZT ceramic to identify the voltage breakdown mechanisms and measure voltage lifetime functions with the coating materials that show improvement.

3.3. PROGRESS

3.3.1. Tests of various conformal coating materials were continued to determine their usefulness as electrical protection for the surfaces of PZT ceramic. The materials tested were generally classified as one of three kinds: (1) epoxy, (2) polyurethane, and (3) acrylic. The material suppliers and coating types from each were as follows:

- Humiseal Division, Columbia Technical Corp.
  Types 1A27, 1A33, 1B31, 2A53, and 2B13.

- Emerson and Cuming, W.R. Grace & Co.
  Types EP3, EC210, VE, VE-FR, and 729.

- Conap, Inc.
  Types CE-1132, CE-1155, CE-1164, and CE-1170.
  Other Conap materials on order for future evaluation are types CE-1171, EN-2, EN-7, and EN-12.

On the basis of physical observation, ten of the coating materials were selected for electrical evaluation on PZT ceramic. These coatings were brush-applied to the PZT insulating surface and allowed to cure according to the manufacturer's recommended time for optimum properties. The specimens were then tested to determine if the coatings had affected the capacitance, dissipation factor, or 1000 V dc resistance. They were then tested to destruction with tests that measured the 60 Hz corona inception voltage (CIV), corona extinction voltage (CEV), and electrical flashover voltage. After this,

the coatings were examined to determine the relative adhesion to the PZT surface. Separate samples of the coating materials were cured to evaluate flexibility and hardness.

Four of these coating materials (1A27, 2A53, CE-1132, and CE-1170) have been selected for further testing. The choice is based mainly on the ability of the coating to increase the CIV of the specimens. Some of the coating materials substantially lower the CIV of the test specimens. Other important differences between the coatings are flexibility and adhesion to PZT. The flexible coatings with good adhesion also tend to have better corona abatement capabilities. Increase of the CIV by the better coating materials is generally small, typically 0 to 5%.

CIV values for 54 specimens of 0.635-cm thickness PZT ceramic were obtained before applying the coating to serve as base line measurements. A histogram showing the distribution of CIV values for the specimen population is shown in Fig. 3.1. The average CIV value for this distribution is 4.91 kV and has a standard deviation of 1.68 kV. The distribution shows a skew to the high end that may be typical of CIV occurrence in sonar transducers.

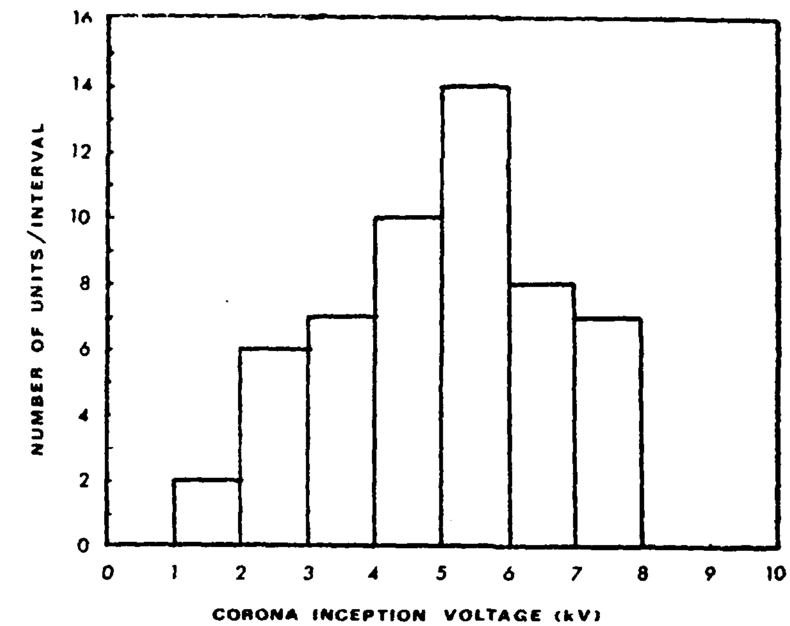

Fig. 3.1 - Distribution of CIV levels for a population of 0.635-cm thickness PZT specimens in air.

3.3.2. Tests were made on two surface modification treatments for PZT ceramic that should reduce corona formation. There is some indication that PZT has an attraction for water molecules and has a layer of water on its surfaces. It is believed that this excess surface water may contribute to the electrical flashover of the PZT surface. The surface treatments investigated are a dip-coating in either difunctional or trifunctional silane. This has the effect of decreasing the surface reactivity to water molecules with the result that the water layer is essentially eliminated.

The difunctional silane treatment appears effective at reducing water adherence to the PZT surface and also raising the CIV of the specimens. However, the dissipation factor and 1000 V dc conductance are increased which indicate a degradation of the insulating properties of the PZT specimens. Further work with this treatment will be limited.

The trifunctional silane treatment also effectively eliminates water adherence to the PZT surface but the CIV is not essentially changed compared to untreated specimens. The dissipation factor and dc conductance are not changed. It is expected that this treatment will be tested to determine its voltage endurance characteristic.

3.3.3. Further evaluation was done on the PZT ceramic doublets of the type used in the Mulloka transducer. Earlier tests[1] showed that the units have a relatively low CIV. Investigation revealed there are three places the hook-up wire insulation can be in contact with or very near the opposite pole electrode. One of these, a jumper wire between the end electrodes, is permanently located so that the wire insulation may be in constant contact with the center electrode. It was determined that bending the jumper wire away from the center electrode greatly increased the CIV. Inspection revealed that the units with higher CIV levels had a finite air gap separation under the jumper wire. Conversely, the units with low CIV levels had the jumper insulation touching the center electrode.

A series of measurements were made to determine the CIV of the hook-up wire as a function of its insulation distance from a plane electrode; the result is shown as curve A in Fig. 3.2. Also, one of the foil electrode solder tabs was removed from a unit and tested separately in a tab-to-plane electrode configuration to determine the CIV as a function of separation distance; this is shown as curve B in Fig. 3.2. These curves indicate that the hook-up wire and solder tabs are contributors to corona formation in the 1.6 to 3.3 kV test voltage range.

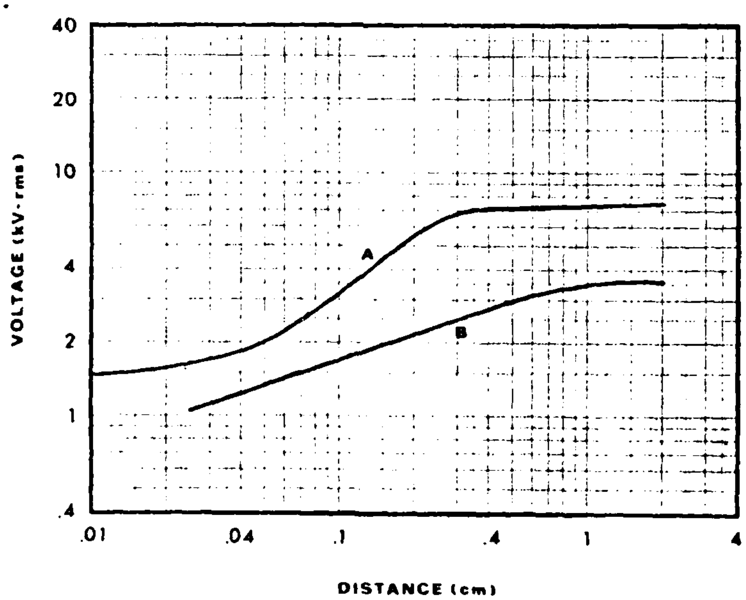

Fig. 3.2 - Hook-up wire (A) and electrode foil (B) corona inception voltage levels in air.

On one of the doublets, the hook-up wiring was removed and new connections installed to determine the CIV level of the Parylene-coated ceramic elements alone. One element measured 5.3 kV and the other 6.2 kV. This is approximately the result to be expected from uncoated ceramic with similar dimensions. The measurements indicate that the Parylene is causing no corona problems due to its presence on the ceramic. In this evaluation, it was not possible to show that the coating was anything more than a neutral influence on the electrical reliability when compared to untreated, clean, dry ceramic. The only benefit of using the Parylene coating is that some protection from contamination to the ceramic surface may be provided, but the dominating contributing factor to corona remains the spacing between the hook-up wires and tabs and the electrodes.

3.4. PLANS

- Measure the voltage endurance function for the four most promising coating materials on PZT ceramic specimens.
- Measure the voltage endurance function for PZT specimens treated with trifunctional silane.
- Evaluate the remaining high dielectric strength coatings on PZT ceramic.
- Write report on test results.

4. TASK C-1 - CABLES AND CONNECTORS

*R.F. Haworth - Electric Boat Division
General Dynamics Corporation*
G.D. Hugus - NRL-USRD

4.1. BACKGROUND

The selection of pressure-proof connectors and cable harnesses for hydrophones and transducers is a critical part of Navy shipboard sonar system design; yet, the design of these components for use in this environment is not covered in any one reference publication. Information on this subject is contained in a multitude of military and industry specifications, standards, and publications. The result is that engineers and designers often duplicate work and may overlook relevant information that they need. Furthermore, most outboard sonar system electrical cables presently in use were designed during or shortly after World War II. As a result, cable designs are limited to the use of elastomeric and plastic materials available at that time. A review of current cable specification and manufacturing processes is needed.

4.2. OBJECTIVES

The objectives of this task are the preparation of a design handbook covering the technology of pressure-proof underwater connectors and cable harnesses for hydrophones and transducers, and the review and development of specifications, more appropriate to the Navy's requirements, for underwater electrical cables.

4.3. PROGRESS

Work on this handbook is being done under contract N61339-80-C-0021 by the Electric Boat Division of General Dynamics Corporation. The contents of the handbook were outlined in two previous quarterly reports.[2,3] The final draft of the handbook is complete - with changes incorporated as a result of reviewers' comments.

Review of cable specifications and practices is also being performed by the Electric Boat Division of General Dynamics Corporation, under contract N00014-81-C-2262.

The first phase of this program is directed to reviewing Navy fleet requirements for outboard cables listed in Table 4.1. This review will include the following cable requirements:

- Insulation resistance
- Withstanding voltage
- Conductor shielding
- Impedance
- Internal waterblocking
- Physical
- Environmental
- Bonding to cable jacket
- Service in stuffing tubes

• Conductor insulation
• Jacket material

Participation will be solicited from Navy laboratories, engineers from the Naval Sea Systems Command, shipyards, transducer repair facilities, Navy users, and cable and sonar system manufacturers. These requirements will be combined realistically with the cable manufacturing capability to provide adequate amounts of cable for transducer manufacture and repair.

The second phase of the task will concentrate on preparing drafts of proposed changes to the MIL-C-915 specification sheets.

Table 4.1 - Navy outboard cables

CABLE TYPE	SPECIFICATION SHEET
DSS	MIL-C-915/8
TSS	MIL-C-915/8
FSS	MIL-C-915/8
7SS	MIL-C-915/8
1SWF	MIL-C-915/47
2SWF	MIL-C-915/48
MWF	MIL-C-915/58
TSP	MIL-C-915/22
DSWS	MIL-C-915/7
S2S	MIL-C-915/61
Various	Sonar System Vendor Specifications

4.4. PLANS

• The handbook will be published during the fourth quarter of FY81, as an NRL Memorandum Report, concluding work on this task.

• Review of Navy requirements for outboard cable (fourth quarter FY81 and first quarter FY82.

• Cable specification draft preparation (second quarter FY82).

• Navy review and final specification draft preparation (third quarter FY82).

5. TASK C-2 - CABLE SHIELDING

H.W. Denny - Georgia Tech Research Institute

5.1. BACKGROUND

Certain advantages such as better water proofing, better water blocking, and lower cost would result from the use of underwater electrical cable without the internal shielding. The use of unshielded versus shielded cable has already been investigated from a mechanical strength viewpoint. The approach will now be to consider the electronics viewpoint of using unshielded or shielded cable on the outboard side of a submarine. Concerns are primarily centered upon electromagnetic interference and ground loops.

5.2. OBJECTIVE

The objective is to determine whether the use of unshielded cable in place of shielded cable, exterior to the hull of a submarine, will affect the electrical performance and reliability of sonar systems.

5.3. PROGRESS

This is a new task in FY81. Work to fulfill this objective is being performed under contract N00014-81-K-2017 by the Georgia Tech Research Institute of the Georgia Institute of Technology.

5.3.1. The approach to the objective will be in three phases:

- Phase 1 - Determination of EMI environment and practices
- Phase 2 - Theoretical modeling
- Phase 3 - Experimental verification

Phase 1 will survey and analyze the installation of the DT-276 hydrophone of the BQR-7 and BQQ-5 systems on submarines to determine the electromagnetic interference (EMI) environment and the present practices of utilizing shielding on cables. Other sonar systems will also be included in the survey to the extent of defining EMI limits, shielding practices, and impedance limits of the hydrophones and signal amplifiers. The results of the survey will be used to determine the correct boundary conditions and parameters or the theoretical modeling. Phase 2 will develop the theoretical modeling of shielded versus unshielded cables necessary and sufficient to predict the electrical performance and reliability of individual and arrays of DT-276 hydrophones in the EMI environment found exterior to the hull of a submarine. The theoretical models and predictions will be generalized beyond the present DT-276 practice to provide for a range of sensor and amplifier impedances and for balanced and unbalanced amplifier inputs. The theoretical modeling will use as a starting point the methods of Dr. Clayton R. Paul as reported in the series of eight volumes of Rome Air Development Center Technical Report 76-101, and be extended to the seawater environment. Phase 3 will devise and implement experimental procedures to verify the predictions obtained from Phase 2 concerning the electrical performance and reliability of hydrophones in the EMI environment exterior to the hull of a submarine. The frequency range of interest is 100 to 20,000 Hz.

5.3.2. The typical cable to be considered here is DSS-3, which means two conductors of Navy size 3 (not AWG) twisted about each other and shielded. At the transducer, the conductors are assumed to be connected to the electrodes of a piezoelectric ceramic element, which appears as a high impedance, capacitive load. The other end of the cable may be connected to a transformer at the input of an amplifier in either the balanced or unbalanced mode, or it may be connected to a high impedance FET on an amplifier input. Current practice appears to be that the shield is often floating or, at most, connected at only one end.

The following represents first considerations of the problem and is abstracted from the previous publications and discussions with Dr. C.R. Paul of the University of Kentucky.

In the typical situation described above, it appears that if the shields surrounding the twisted pair are not grounded on at least one end, they are providing virtually no protection against crosstalk. Because of the high impedance terminations on the twisted pair and the fact that the twist tends to cancel out inductive coupling, it seems that the major contributor to crosstalk between an adjacent, interfering wire circuit and the twisted pair is via capacitive coupling between the two circuits. The main reason for placing a shield around a sensitive wire circuit is to eliminate capacitive coupling to those wires. However, the precise degree to which this takes place depends rather strongly on several factors: the terminal impedances ("high" or "low" impedance loads), the terminal impedance configuration (balanced or unbalanced), and the manner in which the shield is grounded (circumferentially bonded at the connector or pigtailed). Since the terminal impedances are so large, capacitive coupling must surely dominate inductive coupling. On the other hand, capacitive coupling to a balanced twisted pair (unshielded) is essentially eliminated by the balancing of the loads. So on this basis, it probably would not matter in the case of the DT-276 whether the shield is grounded, ungrounded, or removed since the capacitive coupling is probably cancelled by the balanced twisted pair. This, however, is only a first estimate.

5.4. PLANS

Completion of Phase 1 by October 1981.

6. TASK D-1 - ALTERNATIVE MATERIALS: PLASTICS

K. Niemiller - NWSC

6.1. BACKGROUND

Corrosion, cost and acoustic characteristics are parameters that must be considered when selecting a material for the design of a sonar transducer. In the past decade, plastics have decreased in cost and increased in strength to the point that they are in strong competition with metals for specific applications. Plastics could be used as a design material for sonar transducers in order to lower costs and lengthen service life if they can withstand the ocean environment. An additional advantage is that plastics generally are electrically nonconductive and acoustically transparent.

Specifically, the injection molded thermoplastics are the best materials for consideration as an alternative assembly material since they can be molded to close dimensional tolerances and in many configurations. Metals and electronic connectors can be molded directly into the plastics thus reducing the number of separable parts and insuring in-service reliability.

Naval facilities equipped with the proper molding equipment can fabricate replacement parts for sonar transducers when parts are not in stock or readily available. This would be extremely helpful when emergency repair is necessary and the time for normal procurement procedures is not available. In the event that a shortage of material should occur, thermoplastics can be easily recycled.

Presently there are no general long-term ocean immersion data available for thermoplastics. It would take many years of testing and analysis to determine the long-term life expectancy, but there is an immediate need for information. The only approach for determining this information in a reduced time period is to perform accelerated life testing (ALT), but this must be used with caution. When this method is used, it is always recommended that comparison be made to parts which have been exposed to the actual environment in question.

6.2. OBJECTIVE

The objective is to evaluate the ability of plastics to withstand an ocean environment and the reliability of the ALT method for use in determining long-term material life expectancy.

6.3. PROGRESS

The approach to the objective has been to perform a two-year equivalent ALT on eight types of glass-filled thermoplastics. Parallel to this, the same materials will be exposed to an ocean environment for two years. Water absorption, volume change, tensile and shear strength, and sound speed will be measured on all samples. A comparison of the results of the ALT and the ocean test will allow a prediction of the life expectancy of these plastics in sonar application.

Data from the latest ALT are given in Tables 6.1 and 6.2. Shear strengths, as functions of time and temperature, are given in Figs. 6.1, 6.2, and 6.3. Experimental scatter obscures some of the effects but some points should be

noted. Temperature has a distinct effect on the rate of degradation of the properties. For purposes of illustration, the time period to a 20% reduction in shear strength for high-strength nylon was determined from the curves depicted in Fig. 6.3. A plot of the natural log of the reciprocal of this time versus the reciprocal absolute temperature is shown in Fig. 6.4. Linear least squares fit of this data yields an energy of activation for this degradation of 13.7 kcal/mol (57.4 KJ/mol). This value of energy of activation is very near those determined previously by gravimetric methods for other plastics.

All eight materials tested appear to retain shear strength properties better than tensile strength. This will necessitate careful analysis of load forces for any application of these materials.

No additional tests of ocean environment samples were conducted. The next test of ocean environment samples (fifth of seven test intervals) is scheduled for July 1981.

Table 6.1 - Tensile strength (psi)

MATERIAL	% Glass-Filled	Baseline	Temp (°C)	ALT 2048 Hrs.	% of Baseline
Polyphenylene Oxide/ Styrene (Noryl) GE: GFN3	30	15768	10 25 45 75	12897 14458 12332 9902	81.8 91.7 78.2 62.8
Polycarbonate LNP: DF-1008	40	16392	10 25 45 75	15438 15532 7018 7277	94.2 94.8 42.8 44.4
Polysulfone LNP: GF-1006	30	12364	10 25 45 75	11690 11204 10259 9706	94.5 90.6 83.0 78.5
Polyphenylene Sulfide LNP: OF-1008	40	16378	10 25 45 75	13794 13723 15044 13064	84.2 83.8 91.8 79.8
6/10 Nylon LNP: QF-1008	40	19435	10 25 45 75	16939 14996 14311 14072	87.2 77.2 73.6 72.4
PBT Polyester LNP: WF-1008	40	16732	10 25 45 75	16308 16380 13859 6723	97.5 97.9 82.8 40.2
High Strength Nylon LNP: VF-1008	40	15739	10 25 45 75	10508 8963 8713 8016	66.8 56.9 55.4 50.9
Amorphous Nylon LNP: XF-1008	40	19939	10 25 45 75	18902 18516 17505 17343	94.8 92.9 87.8 87.0

Table 6.2 - Shear strength (psi)

MATERIAL	% Glass-Filled	Baseline	Temp (°C)	ALT 2048 Hrs.	% of Baseline
Polyphenylene Oxide/ Styrene (Noryl) LNP: [illegible]	30	8463	10 25 45 75	8441 8501 8715 8736	99.7 100.4 103.0 103.2
Polycarbonate LNP: [illegible]F-1008	40	8229	10 25 45 75	8597 8557 8140 8051	104.5 104.0 98.9 97.8
Polysulfone LNP: GF-1006	30	7922	10 25 45 75	8027 8074 7943 7896	101.3 101.9 100.3 99.7
Polyphenylene Sulfide LNP: OF-1008	40	7669	10 25 45 75	6975 6960 6894 6795	91.0 90.8 89.9 88.6
6/10 Nylon LNP: QF-1008	40	8602	10 25 45 75	8975 8065 7507 7356	104.3 93.8 87.3 85.5
PBT Polyester LNP: WF-1008	40	8349	10 25 45 75	7230 7129 7106 3902	86.6 85.4 85.1 46.7
High Strength Nylon (Zytel) LNP: RF-1008	40	7873	10 25 45 75	5996 4760 4803 4611	76.2 60.5 61.0 58.6
Amorphous Nylon LNP: XF-1008	40	9733	10 25 45 75	8907 8205 8877 9694	91.5 84.3 91.2 99.6

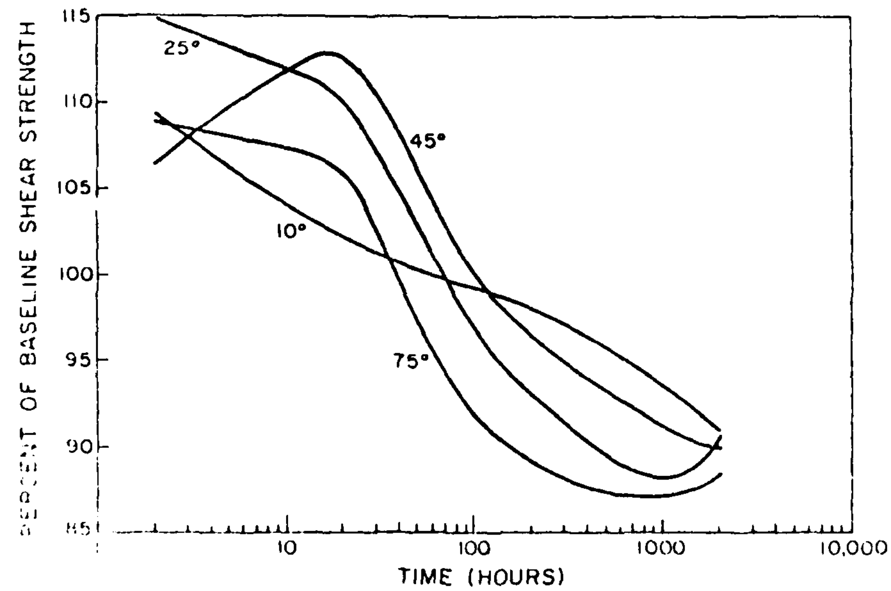

Fig. 6.1 - Shear strength of polyphenylene sulfide exposed to seawater.

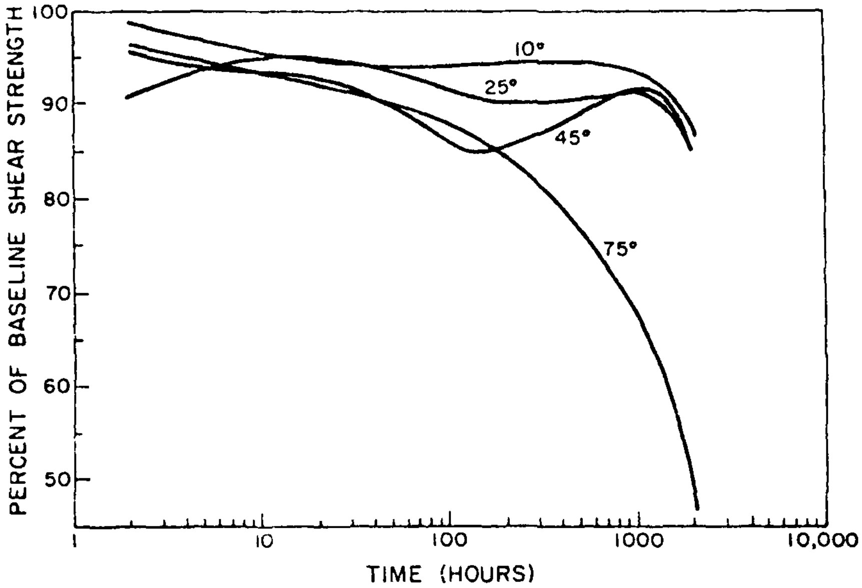

Fig. 6.2 - Shear strength of PBT polyester exposed to seawater.

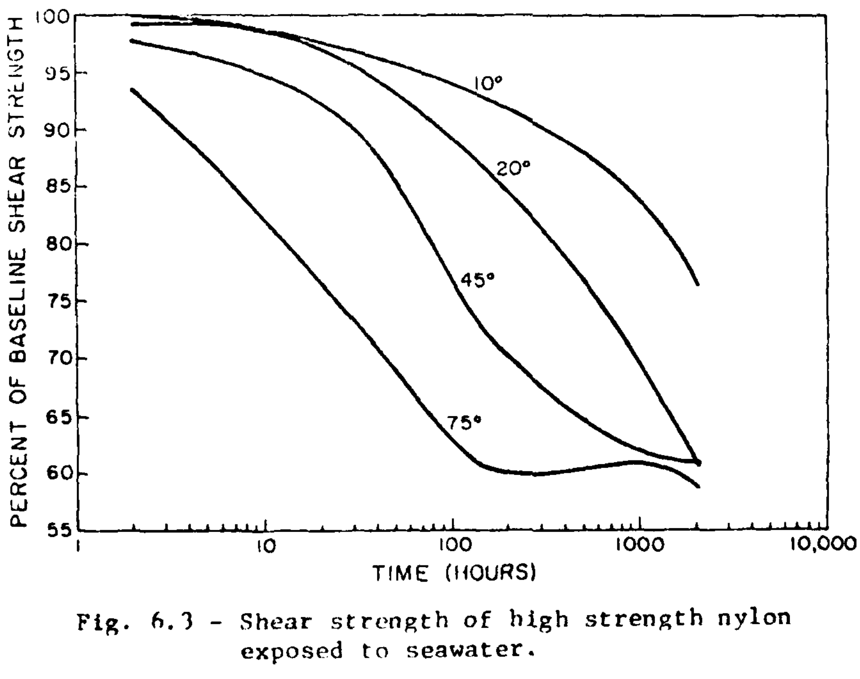

Fig. 6.3 - Shear strength of high strength nylon exposed to seawater.

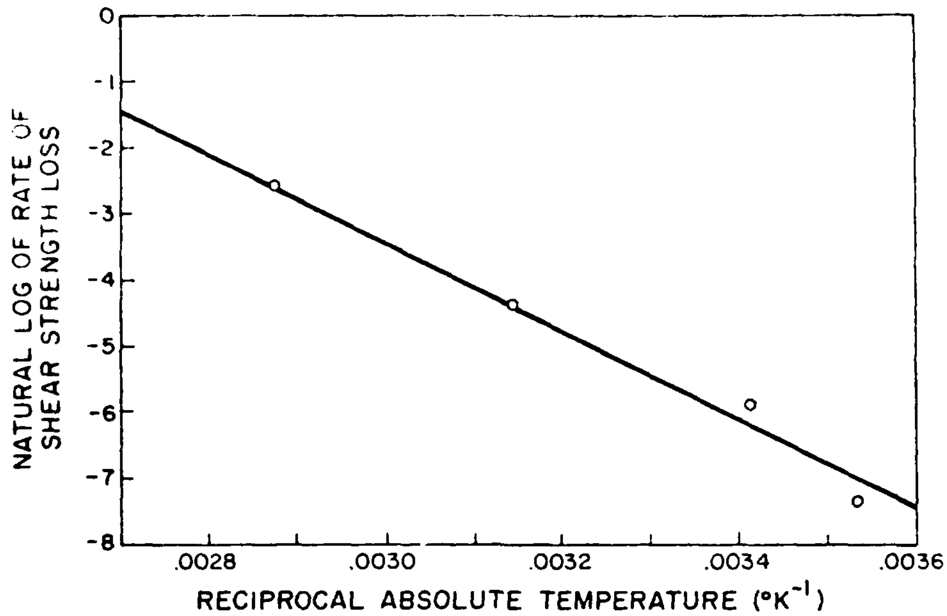

Fig. 6.4 - Arrhenius plot for the degradation of the shear strength of high strength nylon.

6.4. PLANS

- Complete analysis of ALT data.
- Submit interim technical report on ALT findings.
- Continue ocean environment exposure.
- Prepare procedures for evaluating creep, stress degradation, and machined plastics degradation.

7. TASK D-3 - SPECIFICATION FOR TRANSDUCER ELASTOMERS

C.M. Thompson - NRL-USRD

7.1. BACKGROUND

The high cost of maintenance, replacement, and repair of fleet transducers has become so inhibitive that the reliability of sonar transducers has received a great deal of attention in recent years. Improvement in the reliability of such systems through failure analysis and material development and modification is emphasized. It is hoped that such an effort will, in the end, provide the fleet with more effective systems having an extended operational lifetime and also that the overall life cycle cost will be minimized. Indeed, the most severe stress that can be imposed on a system or the materials used in the system is that of time. The necessity of a transducer elastomer to maintain its physical strength, electrical resistivity, and acoustic properties in the face of years of temperature extremes, UV radiation, seawater, pollutants, and physical abuse is a most difficult requirements. Small wonder then that transducer elastomers have been the source of a large proportion of failures in sonar transducers.

The most frequent scenario for the choice of a transducer elastomer is that the design engineer, having developed a list of performance requirements, requests from a rubber manufacturer a material to meet these requirements. Unfortunately, the performance requirements are frequently, at best, an educated "guess" of the properties expected of the material based on past experiences. The requirements list may not include all of the important short-term properties and likely will not include any long-term properties. Consequently, the material developed by the rubber manufacturer is not likely to have been optimized for short-term operation; moreover, it may not even have been considered in its design for the extended lifetime performance required in a sonar transducer system.

A recent example of this type of failure has been with a neoprene rubber formulation which was designed to meet a variety of specification tests. Unfortunately, the specification did not require a high electrical resistance after water immersion and this deficiency has apparently produced an alarmingly high rate of transducer failure.

It is therefore desirable to establish specifications for transducer elastomers that are based on a consideration of all the stresses imposed. This requires that the performance of transducer elastomers, both initial and long-term properties, be well understood as functions of elastomer composition, cure conditions, and environmental parameters. Only then can the composition and processing procedures of the elastomers be carefully chosen and specified. In this task, the results obtained in other more basic R&D programs will be incorporated in the development of specifications for transducer elastomers. Appropriate engineering studies will also be carried out for candidate materials as needed so that the preparation of complete rubber specifications may be possible.

7.2. OBJECTIVE

The objective of this task is to establish specifications for elastomers for use as transducer windows and cable jackets.

7.3. PROGRESS

7.3.1. Under funding support of the Sonar Transduction Science Program (Program Element 62711) instrumental techniques have been developed for the compositional analysis of a neoprene rubber, Neoprene 5109. This Navy-developed elastomer was considered most suitable for underwater sound application as confirmed by recent progress in that program. By using techniques including HPLC and GPC, a series of studies was conduc ed to relate the analyzed composition of the material to their physical properties. The results allow one to establish limits on the deviations of composition such that elastomer composition may be fine-tuned for specific applications.

This work is being transitioned to the STRIP for preparation of procurement specifications. The specifications will include composition and methods of compositional analysis for Neoprene 5109. The first draft will be published for comment during the fourth quarter of FY81.

7.3.2. The study into the effect of composition on degradation properties of Neoprene GRTs is continuing. This study is in support of the failure mode analysis for a fleet transducer. The results to date have elucidated the rate of absorption of water by the elastomer. Table 7.1 shows a comparative rate of absorption for several vulcanizing agents. It is clear from this result that the type of metal oxide used has a drastic effect on the water permeation.

Table 7.1 - Effect of type of vulcanizing agent on the water absorption rate.

METAL OXIDE	GRAVIMETRIC RATE
Pb_3O_4 15 phr	1.6×10^{-4} $hr^{-1/2}$
ZnO-5+MgO-4 phr	13×10^{-4}
ZnO-8+MgO-1 phr	9.6×10^{-4}
ZnO-10 phr	4.3×10^{-4}

Table 7.2 illustrates the effect of changes in the particle size of the carbon black on the rate of water uptake. Although the results show some effect of experimental scatter, it is clear that the finer carbon black produces a material which absorbs water much faster than the courser blacks.

Table 7.2 - Effect of size of carbon black on the water absorption rate.

TYPE OF BLACK (QUANTITY)	HARDNESS	PARTICLE DIAMETER	GRAVIMETRIC RATE
HAF (37 phr)	67	26 nm	12×10^{-4} $hr^{-1/2}$
FEF (50 phr)	68	46 nm	1×10^{-4}
SRF (60 phr)	65	73 nm	1.8×10^{-4}

Table 7.3 illustrates that one classical method of lowering water uptake, i.e., the replacement of part of the carbon black by silica or clay, does not seem to be effective in this case.

Table 7.3 - Effect of the type of filler on the water absorption rate.

FILLER	HARDNESS	GRAVIMETRIC RATE (25°C)
FEF 40 phr	59	1.6×10^{-4} $hr^{-1/2}$
FEF-30, HiSil-10 phr	55	2.3×10^{-4}
FEF-30, Clay-10 phr	52	1.4×10^{-4}
FEF-30, HiSil-10-ZnO-5, MgO-4	68	9.3×10^{-4}

Permeability testing of this same series of samples is near completion. The permeability results are expected to track the gravimetric results, and to yield data which can be more readily used for calculating failure rates. In addition, the volume resistivity of these samples is also being measured as a function of water exposure. This evaluation is important because it was recently revealed that transducer failures may be related to the drastic changes in electrical properties of elastomers when wet. Upon the completion of this series of tests the preparation of a draft specification for Neoprene 5109 will begin.

7.4. PLANS

- Complete study on compositional changes on Neoprene GRT and report results (15 Jul 1981).

- Perform study on transducer-related properties of Neoprene 5109 (30 Jul 1981).

- Prepare draft specification for Neoprene 5109 (30 Sep 1981).

8. TASK D-4 - TRANSDUCER CERAMICS

A.C. Tims - NRL-USRD

8.1. BACKGROUND

Because of the fragile nature of piezoceramic ceramic materials, transducers using these materials are shock hardened by the technique of winding glass filament under tension onto the ceramic element to produce a constant compressional stress in the ceramic material. The compressional bias reduces the probability of tensional fracture of the ceramic when subjected to high acceleration due to explosive loading. However, variations in the winding technique may produce a variability in the finished transducer element that greatly exceeds any variability in the properties of the ceramic itself.

8.2. OBJECTIVES

The objectives are to investigate and determine the effects of filament winding on peizoelectric ceramic in transducer configurations and to develop a standard procedure for the fiberglas wrap process used on ceramics in sonar transducers.

8.3. PROGRESS

It is well known that fiber wrapping of ceramics causes significant changes in the electromechanical coupling coefficients k_{31} and k_{33}, and also changes in the capacitance and dissipation factor, but this investigation is not primarily concerned with these changes. This investigation is concerned as to why a specific group of ceramics can show greater statistical variations in properties after fiber prestressing than before.

The general procedure to fiberglas prestress a cylinder, ring, or stack is to wind a number of layers of continuous fiberglas roving onto the ceramic while simultaneously applying an epoxy resin coating. The roving is applied under constant tension in a number of layer-turns that will produce the required prestress. The magnitude of the prestress is determined in various manners with the exact method usually determined by a manufacturer's past experience. The contemporary method of determining prestress magnitude is to use resistance strain guages, Hooks Law, and shell theory.

There is little formal documentation on the processes or techniques involved in the fiberglas prestressing of ceramic elements for use in sonar transducers. It appears that the specific technique and equipment used by a manufacturer have been developed in-house to meet certain manufacturing requirements or specifications in transducer contracts. There are several variables involved in the process that could potentially cause variations in the finished product such as filament material properties, resin type, wrapping tension, and resin cure cycle. The consistency of glass-wrapped ceramics could be improved by adoption of standard procedures for the process, but no such standard procedure exists.

It appears at this point in the investigation that there are two major causes for the variability between fiberglas-wrapped ceramics. The first may be due to variations in the winding tension from ceramic to ceramic. If the

winding tension is not constant from ceramic to ceramic, one could not expect the electromechanical parameters to be as statistically uniform after wrapping as they were before wrapping. The second cause is probably intrinsic to the ceramic itself. If the diameters of the ceramic are not concentric, or the shape is ellipsoidal, the stresses in the wall will not be uniform. In this case, the winding tension could be constant from ceramic to ceramic but the end results would show greater variations in the electromechanical parameters after wrapping.

Forty-four ceramic cylinders with a wall thickness to diameter ratio of 0.05, fully machined to close dimensional tolerances, have been selected for prestressing. The 44 were divided into equal lots, electromechanical values were carefully determine, and then they were sent to two manufacturers for fiberglas wrapping. It is expected that if the manufacturers' techniques are uniform the electromechanical parameters measured after wrapping will be uniform. Conversely, any variations should be the direct result of variations in the winding technique.

The prestressed cylinders were returned to NRL-USRD, but not in enough time to measure them and report the results this quarter.

8.4. PLANS

- Complete measurements on prestressed rings and document the results indicating the variations between manufacturers and within each lot.
- Develop an in-house fiber-wrap capability at NRL-USRD to evaluate all facets of the prestress process and technique.
- Obtain data on the effects of fiberglas prestress for statistical analysis and data base from new transducer contracts via Contract Data Requirements Lists.

9. TASK E-1 - STANDARDIZED TEST PROCEDURE

J. Wong - NOSC

9.1. BACKGROUND

It is at present not possible to subject a transducer specimen to a series of environmental stresses over a short time period and prove, if it passes certain operating parameter tests, that the specimen is a reliable transducer with a certain minimum expected life in fleet use. Of course, if we could simply use a set of transducers for the desired fleet life, we could check the failure rates against acceptable replacement or repair rates; but the approach here is to accelerate the environmental stress actions and thereby subject the transducer specimen to seven years of life cycle stresses in a few weeks or months.

9.2. OBJECTIVE

The objective of this task is to develop a set of standardized procedures based on environmental stress requirements to accelerate the aging of transducers.

9.3. PROGRESS

9.3.1. DT-605 Hydrophones and TR-316 Projectors

Composite unit accelerated life tests (CUALT) on two Hazeltine Corporation DT-605 hydrophones (serials A1 and A5) and two Ametek/Straza TR-316 projectors (serials A1 and A3) continued. The DT-605 hydrophones are in the fifth-year equivalent of CUALT while the TR-316 projectors A1 and A3 are in the second- and third-year equivalent of CUALT respectively.

Due to the prolonged maintenance shutdown of the pressure testing facility at the Naval Ocean Systems Center (NOSC) the pressure cyclings and pressure dwells exposure for the CUALT was accomplished at the Deep Ocean Lab of the Naval Civil Engineering Laboratory, Port Hueneme, CA, in April 1981. The pressure cyclings and dwells (Table 9.1 of the STRIP FY80 Fourth Quarter Progress, NRL Memorandum Report 4328) were required to complete the fourth- and second-year equivalent of CUALT for the DT-605 and the TR-316 respectively. To utilize the idle time while waiting for the pressure cycling exposure to complete the fourth-year equivalent on the DT-605, the 655 hours of 71°C dry heat aging and duty-cycle increase exposure for the fifth-year equivalent was performed.

Acoustic check on the two DT-605's was done after the completion of the fourth-year equivalent CUALT and the 71°C dry heat exposure. Figures 9.1 through 9.4 show the receive sensitivities of hydrophones A1 and A5. Each DT-605 has four staves, two narrow-beam staves (staves 1 and 2) and two wide-beam staves (staves 1 and 2). The narrow-beam staves of the two hydrophones (Figs. 9.1 and 9.3) are still within the DT-605 Critical Item Production Specification (CIPS). There is a slight trend of decrease in the receive sensitivity with increasing number of years equivalent of CUALT, especially at the higher frequencies of the operating band.

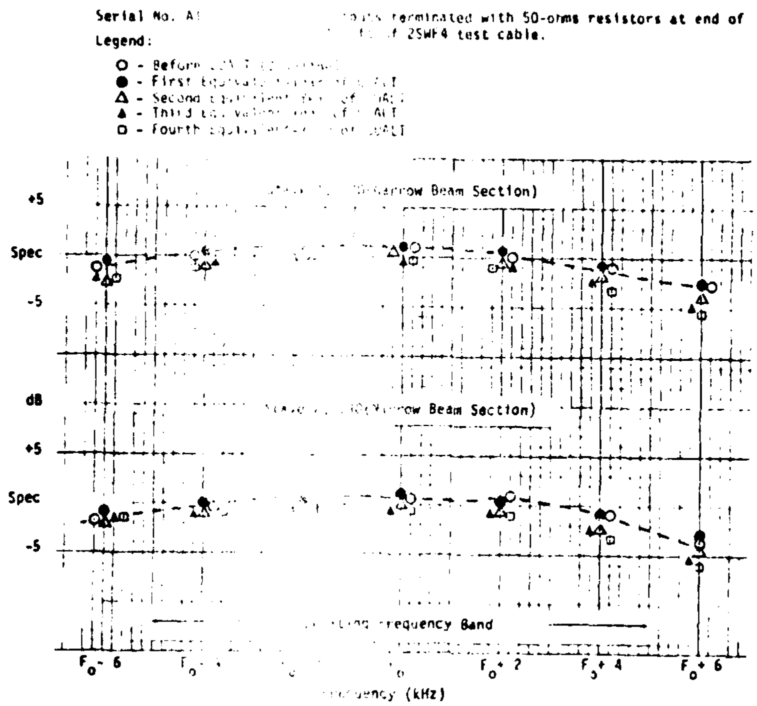

Fig. 9.1 - Receive sensitivity of Hazeltine DT-605 after four-years equivalent of CUALT.

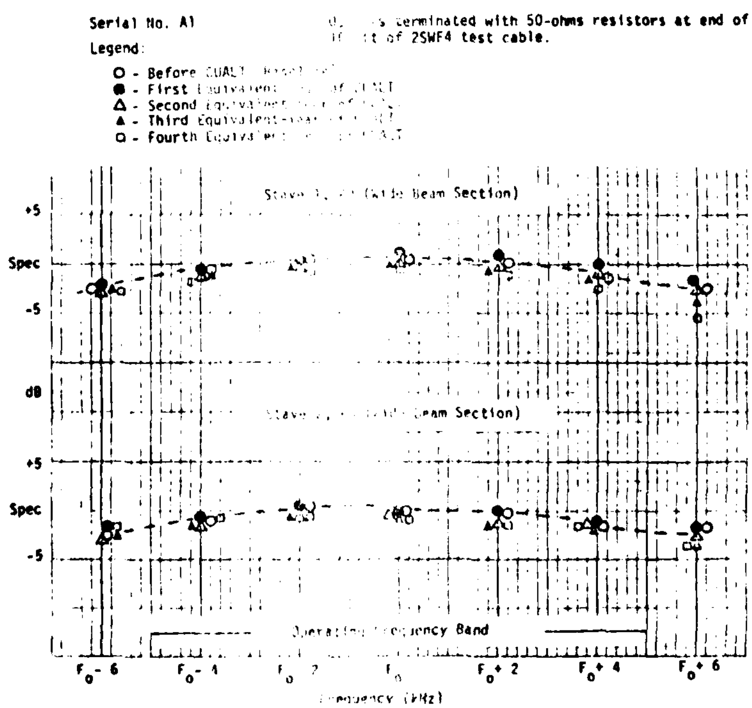

Fig. 9.2 - Receive sensitivity of Hazeltine DT-605 after four-years equivalent of CUALT.

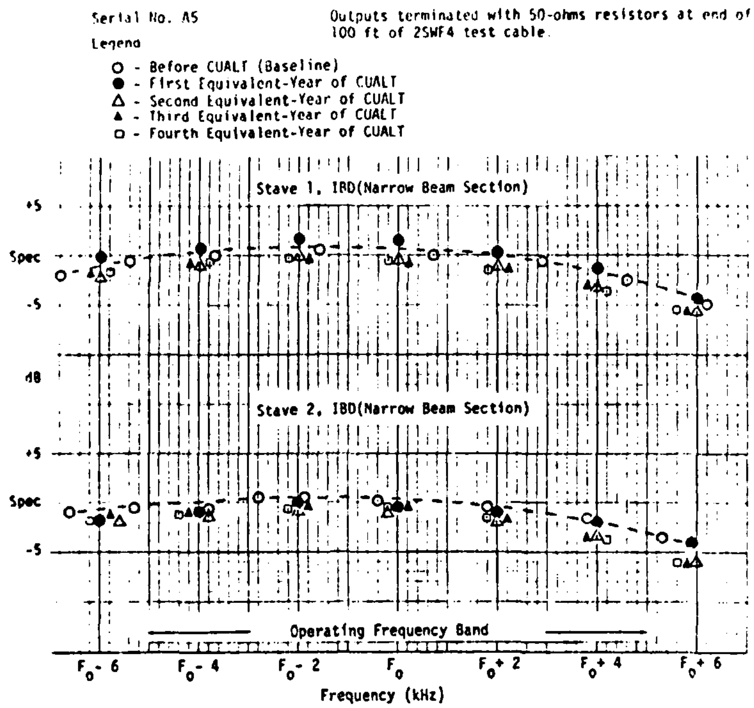

Fig. 9.3 - Receive sensitivity of Hazeltine DT-605 after four-years equivalent of CUALT.

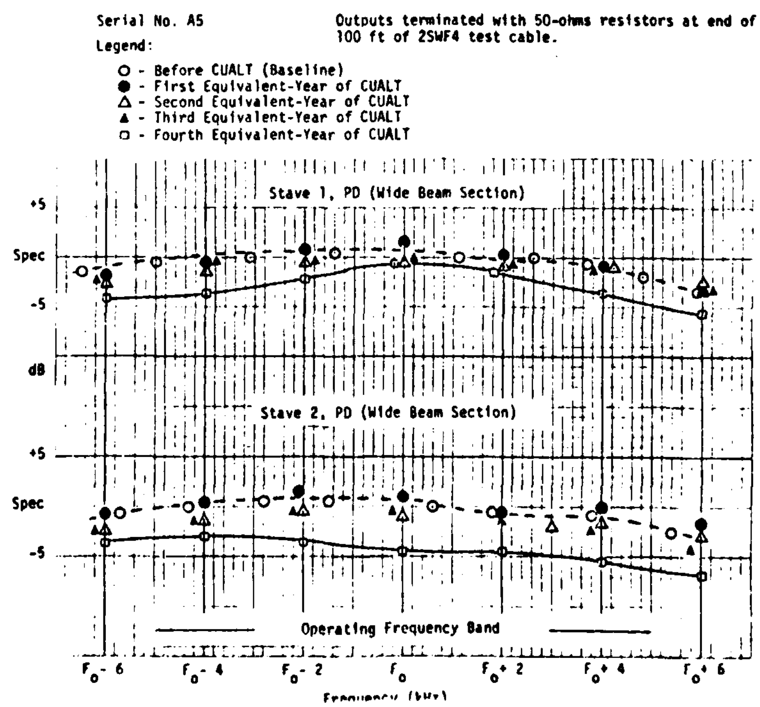

Fig. 9.4 - Receive sensitivity of Hazeltine DT-605 after four-years equivalent of CUALT.

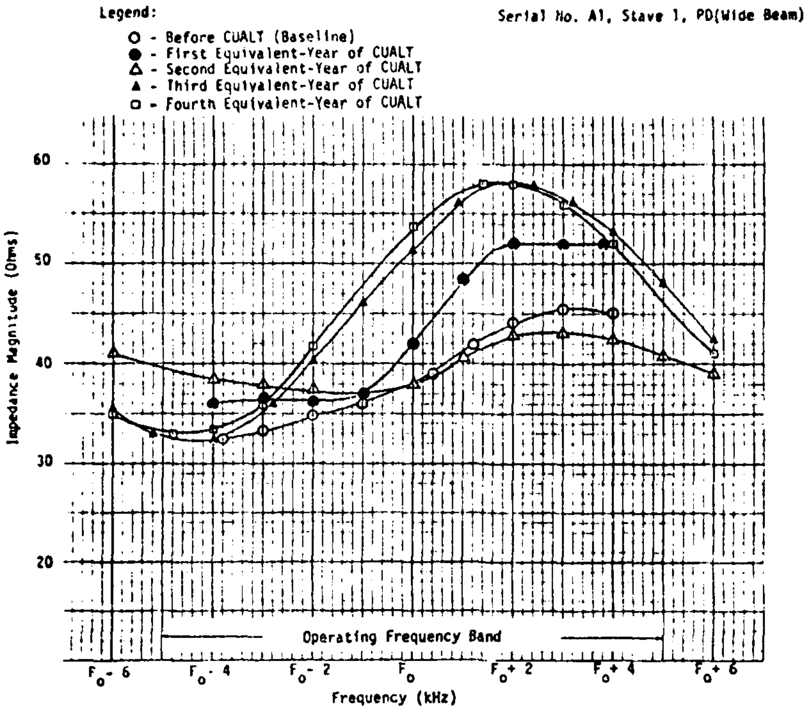

Fig. 9.5 - Impedance Magnitude of Hazeltine DT-605 after four-years equivalent of CUALT.

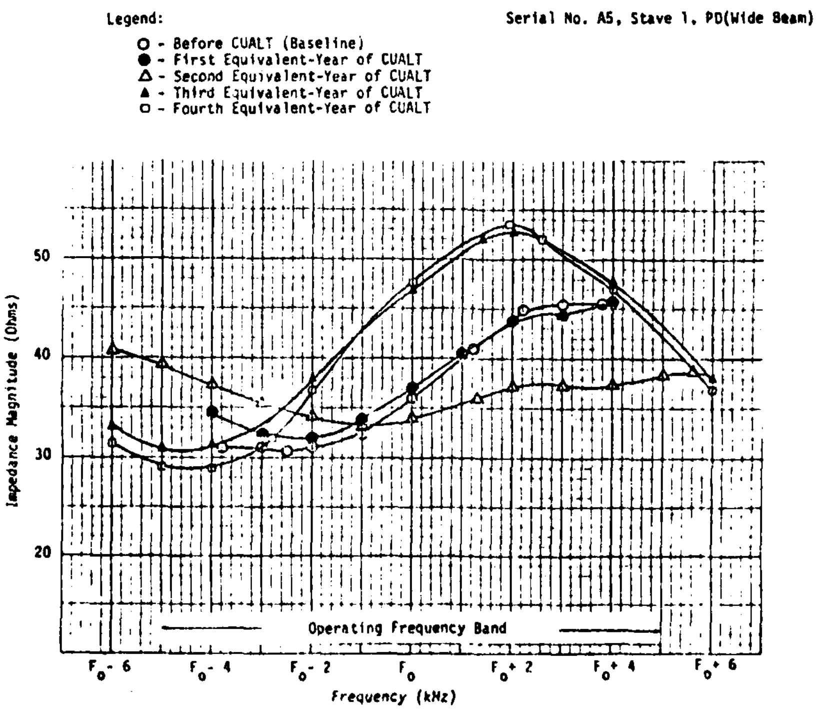

Fig. 9.6 - Impedance Magnitude of Hazeltine DT-605 after four-years equivalent of CUALT.

The wide-beam staves receive sensitivities are shown in Figs. 9.2 and 9.4. Both wide-beam staves 1 and 2 of hydrophone A1 (Fig. 9.2) still meet specifications. However, the receive sensitivities of the two wide-beam staves of hydrophone A5 do not meet specifications (Fig. 9.4). Stave 1 meets the specifications at the center-band frequency F_o, but dropped 2 to 3 dB below the values measured at the end of the third-year equivalent CUALT in the extreme low and high frequency ranges of the band. Stave 2 is approximately 4.5 dB below the specifications at the center-band frequency F_o, which is well outside of the ±1.5 dB tolerance at F_o as required in the CIPS. Furthermore, the receive sensitivity has deteriorated approximately 3 dB below the third-year equivalent values across 80% of the upper operating frequency band. A word of caution, however, is that these data are in question and the changes may not be as drastic as indicated above. This question will be checked carefully.

The input impedance mangitudes of all the staves, except two, remained within the CIPS requirement of less than 50 ohms in the operating frequency band. The two staves that do not meet specifications are the wide-beam stave 1 of hydrophones A1 and A5, shown in Figs. 9.5 and 9.6 respectively. Hydrophone A5 has only a marginal increase (maximum of only 3.5 ohms) above the specification limit of 50 ohms over a frequency band of 2 kHz (F_o + 1 to F_o + 3 kHz), while the wide-beam stave 1 of hydrophone A1 has a maximum of 8 ohms above the specification limit over a wider frequency band of 5 kHz (F_o - 0.5 to F_o + 4.5 kHz). Note that the impedance magnitudes of these two staves have not changed significantly between the third- and fourth-year equivalent CUALT.

No apparent correlations were observed between the degradations of the DT-605 receive sensitivity and the increase in the input impedance. Beam patterns could not be taken at this time due to the breakdown of testing equipment. The acoustic data will be rechecked for accuracy at the earliest opportunity.

The TR-316 projector A1 started the second-year equivalent of CUALT with the electrical high drive on the up- and narrow-beam sections, the pressure cyclings and dwells in April 1981, and followed with the thermal shocks (high and low temperature) and 60 hours of 71°C fresh water soak exposures in late May 1981. Projector A3 started the third-year equivalent with the thermal shocks and 71°C water soak. These two units are now undergoing electrical high-drive exposure. Only the down-beam section of projector A1 is being exposed to high-drive at this time to complete the second-year equivalent of electrical high-drive for all three beam sections of this unit. The down-beam section resonators are one-year equivalent behind in the high-drive exposure because these resonators were replacements for the beam section which failed during the first-year equivalent CUALT.

After the thermal shocks and 71°C fresh water soak exposures, projectors A1 and A3 were probed for air bubbles. As reported in the STRIP FY80 Fourth Quarter Progress, air bubbles of substantial size (3 to 5 cm) were found in the up- and narrow-beam sections of projector A3 after the first-year equivalent CUALT. An air bubble approximately 4-cm wide has now been detected in the down-beam section that was not detected earlier. Also, smaller air bubbles (2-cm wide) in both wide-beam sections of projector A1 were detected for the first time. A cursory check of the source per volt, input impedance,

and beam patterns of projector A3 before commencing the present high-drive indicate that the air bubbles have not affected its acoustic performance - it is still within specifications.

9.3.2. Report on FY CUALT Effort

A report on the CUALT of the DT-605 hydrophones and the TR-316 projectors during FY80 is being completed.

9.4. PLANS

- Continue with CUALT on DT-605 to complete six-years equivalent in FY81.
- Continue with CUALT on TR-316 to complete three-years equivalent in FY81.
- Complete final report on FY80 CUALT effort.

10. TASK E-2 - ACCELERATED LIFE TEST VERIFICIATION

A. Phipps and *D. Steele - NWSC*

10.1. BACKGROUND

Until recently, sonar transducers that were used in the fleet were fabricated and put into operation with limited life testing. Some units performed quite well throughout the expected service life while other exhibited an early high-failure rate. Costs of transducers have increased dramatically and the life requirements have been increased to fit new overhaul schedules. These and other factors have mandated verifying the reliability of units for the entire service life. In order to determine the reliability of transducers for a given time of service, it was determined that the approach of composite unit accelerated life tests (CUALT) should be used. This method not only investigates the physical degradation of the materials used in the transducer assembly, but also the susceptibility of mechanical or electrical failures. Just as accelerated life tests (ALT) for materials need to be verified by using specimens that have been exposed for the full duration to the environment being evaluated, this must also be done for CUALT.

In July 1978, a complete array of 48 DT-168B hydrophones was removed from the USS STONEWALL JACKSON (SSBN-634) and retained intact for post-service evaluation at the Naval Underwater Systems Center (NUSC) in New London, CT. This array of hydrophones had undergone extensive evaluation at NUSC before being installed in the SSBN-634. It was decided that these hydrophones could be used to verify the acceptability of using CUALT for hydrophones.

The DT-168B is the passive sensor for the AN/BQR-2 sonar system. This set of 48 hydrophones was fabricated by the Naval Weapons Support Center, Crane, IN, in 1972. Three sets of five air-backed cylindrical ceramics made of lead-zirconate-titanate (PZT-5A) wired in parallel series are the main internal electrical components. The ceramics are protected by a steel cage that is covered by a butyl rubber acoustic window. The elements are isolated from the cage by rubber grommets. Shielded DSS-3 cable 38-m long is used to connect each hydrophone to the system.

By fabricating ten hydrophone units identical to those in the array and performing an established CUALT on these units, it will be possible to compare the degradation of these units to the information retrieved from the post-service hydrophones.

10.2. OBJECTIVE

The objective is to verify the accuracy of the CUALT method by comparing results with a known real-time life test.

10.3. PROGRESS

As stated in the STRIP FY81 Second Quarter Progress Report, the ten DT-168B hydrophones began the ALT portion of the CUALT. The ALT is scheduled to run six cycles consisting of salt water immersion and pressure cycling. The test began on 1 April 1981 and has now completed three cycles. The salt water immersion portion of the fourth cycle has been completed and the hydrophones

are waiting the start of the fourth cycle pressure cycling. However, due to high priority testing being done at the pressure cycling facility, a set-back of the test schedule has developed. It now appears that the test will not be completed until the end of August 1981.

Data have been collected during and after all tests and, upon completion of the ALT, the data will be evaluated and the reliability of the CUALT will be determined.

Tables 10.1 through 10.4 show values of capacitance and insulation resistance that were taken after each test. Serials 0124 and 0147 are two post-service hydrophones which are being tested along with the special DT-168B's. Serial 0124 developed a leak during cycle 1 of the ALT as was indicated in an earlier report. Data are shown for testing done after production, hydrostatic pressure, qualification, and lake tests, and after each completed cycle of ALT. Some degree of degradation can be seen from this data. It is anticipated that the degradation will continue through the remainder of the ALT at which time the total degradation and rate of degradation will be compared and evaluated with data from the post-service array. The only foreseeable problem continues to be scheduling of the pressure cycling facility.

Table 10.1 - Capacitance (nF)

SERIAL	PRODUCTION	HYDROSTATIC PRESSURE	QUALIFICATION	LAKE TESTS*	CYCLES 1	2	3
1	19.41	16.02	17.66	16.54	-	16.46	16.94
2	20.00	16.88	18.47	17.20	-	17.14	17.58
3	19.58	16.53	18.08	16.95	-	16.97	17.31
4	19.63	16.44	18.10	16.85	-	16.68	17.24
5	19.53	16.41	18.07	16.90	-	16.78	17.28
6	19.15	15.98	17.52	16.38	-	16.38	16.89
7	19.25	16.09	17.58	16.53	-	16.40	16.90
8	19.33	16.05	17.73	16.59	-	16.48	17.00
10	19.75	16.69	18.20	16.83	-	16.67	17.15
0124	-	15.63	16.92	17.09	-	-	-
0147	-	15.77	17.01	17.20	-	17.10	17.49

* 65' cables with connectors - add 1.6 nF to readings to compare with previous readings

Table 10.2 - Insulation resistance (GΩ) between black-white leads

SERIAL	PRODUCTION	HYDROSTATIC PRESSURE	QUALIFICATION	LAKE TESTS	CYCLES 1	CYCLES 2	CYCLES 3
1	12.0	4.70	2.35	1.10	0.090	0.167	0.355
2	12.3	5.14	2.10	1.11	0.980	0.912	1.09
3	13.0	5.90	2.00	4.2	0.690	0.582	0.738
4	13.5	4.85	2.20	1.19	0.450	0.720	0.817
5	14.5	4.54	2.05	1.00	0.041	0.354	0.535
6	14.0	5.65	1.85	1.16	1.12	1.02	1.40
7	13.5	5.65	1.59	1.13	0.196	0.728	0.932
8	13.5	4.54	2.15	1.12	0.510	0.830	0.895
10	13.2	5.26	1.53	1.08	0.880	0.270	1.05
0124	-	0.515	0.91	1.00	-	-	-
0147	-	0.520	1.07	1.01	0.910	1.00	0.950

Table 10.3 - Insulation resistance (GΩ) white case

SERIAL	PRODUCTION	HYDROSTATIC PRESSURE	QUALIFICATION	LAKE TESTS	CYCLES 1	CYCLES 2	CYCLES 3
1	3.00	3.83	0.50	0.310	0.225	0.055	0.200
2	3.10	4.00	0.49	0.280	0.240	0.213	0.247
3	2.95	4.68	0.49	0.195	0.221	0.180	0.207
4	3.00	3.76	0.50	0.300	0.226	0.252	0.218
5	2.90	3.57	0.49	0.270	0.190	0.185	0.212
6	2.00	4.40	0.46	0.280	0.255	0.233	0.228
7	2.95	6.50	0.42	0.280	0.200	0.228	0.203
9	3.10	3.65	0.49	0.270	0.205	0.240	0.205
10	3.10	4.45	0.41	0.270	0.208	0.240	0.224
0124	-	0.565	0.31	0.270	-	-	-
0147	-	0.600	0.32	0.265	0.233	0.283	0.222

Table 10.4 - Insulation resistance (GΩ)
black case

SERIAL	PRODUCTION	HYDROSTATIC PRESSURE	QUALIFICATION	LAKE TESTS	CYCLES		
					1	2	3
1	2.85	5.83	1.25	0.780	0.325	0.295	0.410
2	3.00	6.11	1.02	0.810	0.780	0.800	0.910
3	2.90	5.90	1.18	0.215	0.650	0.520	0.670
4	2.85	5.99	1.26	0.840	0.460	0.648	0.712
5	2.90	5.61	1.25	0.750	0.220	0.360	0.525
6	2.90	6.80	1.06	0.830	0.990	0.875	0.962
7	2.95	3.95	0.95	0.845	0.320	0.640	0.815
8	3.00	5.99	1.21	0.800	0.550	0.700	0.769
10	3.00	6.08	0.93	0.800	0.720	0.120	0.848
0124	-	1.96	0.67	0.715	-	-	-
0147	-	1.97	0.68	0.725	0.690	0.800	0.760

10.4. PLANS

- Complete ALT.
- Test and evaluate the hydrophones and data for degradation of physical and electrical properties.
- Compare the test data with that of post-service hydrophones for determination of CUALT reliability of effectiveness.

11. TASK F-1 – ENGINEERING ANALYSIS: FAILURE MODES DUE TO WATER

[illegible] – Texas Research Institute, Inc.

11.1. BACKGROUND

The state of water which enters a transducer and its effect once inside are continuing problems in the sonar community. Important questions are:

- What impurities come through rubber seals with water permeation?
- Where is the internal water, adsorbed or vapor?
- What temperatures or heat flows occur whithin transducers when the ambient temperature changes or the device is driven?
- What value is desiccant in a transducer?
- How can the lifetime of a transducer be accelerated?

11.2. OBJECTIVE

The objective is to determine the effects of water or water vapor on the performance and lifetime of sonar transducers and hydrophones. Specifically, the effects of the neoprene seals on the permeant (and vice versa) and the electronic changes caused by the permeant are to be investigated.

11.3. PROGRESS

11.3.1. Electronic Characterization of TR-208A Transducers

Three TR-208A transducers were prepared at TRI and sent to NRL-USRD for electronic characterization tests including free-field voltage sensitivity (FFVS), transmitting voltage response (TVR), transmitting current response (TCR), and directional response (DR). The three conditions under which the transducers were tested have been labeled dry, wet, and aged. The dry condition was achieved by flushing the transducers internally with air dried with magnesium perchlorate, a very efficient desiccant. The wet condition was obtained by internal flushing of the transducers with a 55% relative humidity (RH) atmosphere that was generated by a saturated solution of magnesium nitrate. Aging of the transducers was accomplished by flushing them with an 89% RH atmosphere (saturated solution of potassium nitrate), oven heating for 30 days at 70°C, then equilibrating at 55% RH just prior to characterization.

It should be noted here that the electronic characterization data were gathered under greatly varying conditions of temperature and pressure. Because only two transducers, serials 16955 and 17161, were subjected to aging they will be the only ones presented in this report. The final report will contain all data gathered during the performance period.

<u>Free-Field Voltage Sensitivity</u> – Figure 11.1 shows the degree to which the presence of water vapor in and aging of a TR-208A can change its FFVS. The

peaks for serial 16955 were shifted from 2.8 kHz for the dry condition to 2.7 kHz for wet, and 2.4 kHz for aged. Peak heights also varied greatly for dry, wet, and aged. They were -167, -173, and -185 dB, respectively. For transducer serial 17161 the peak representing the wet condition shifted slightly to the right of the dry condition peak, 2.7 kHz dry and 2.8 kHz wet. The peak for the aged condition was shifted in the same direction as that for serial 16955, 2.55 kHz. Peak heights were -168, -169, and -176 dB for dry, wet, and aged conditions, respectively.

Transmitting Current Response - Very significant changes in TCR are evident for the three test conditions, comparable to FFVS in Fig. 11.1. As in the FFVS data, the curves for the aged conditions show the most radical changes. For transducer serial 16955 the peaks shifted from 2.8 kHz dry to 2.5 kHz wet and 2.4 kHz aged. The largest variation was in peak height: 195 dB dry, 184.5 dB wet, and 176.5 dB aged. Transducer serial 17161 again showed a shift to higher frequency for the wet condition--2.8 kHz compared to 2.6 kHz for the dry transducer. The aged curve showed behavior similar to serial 16955 although without as pronounced a changed.

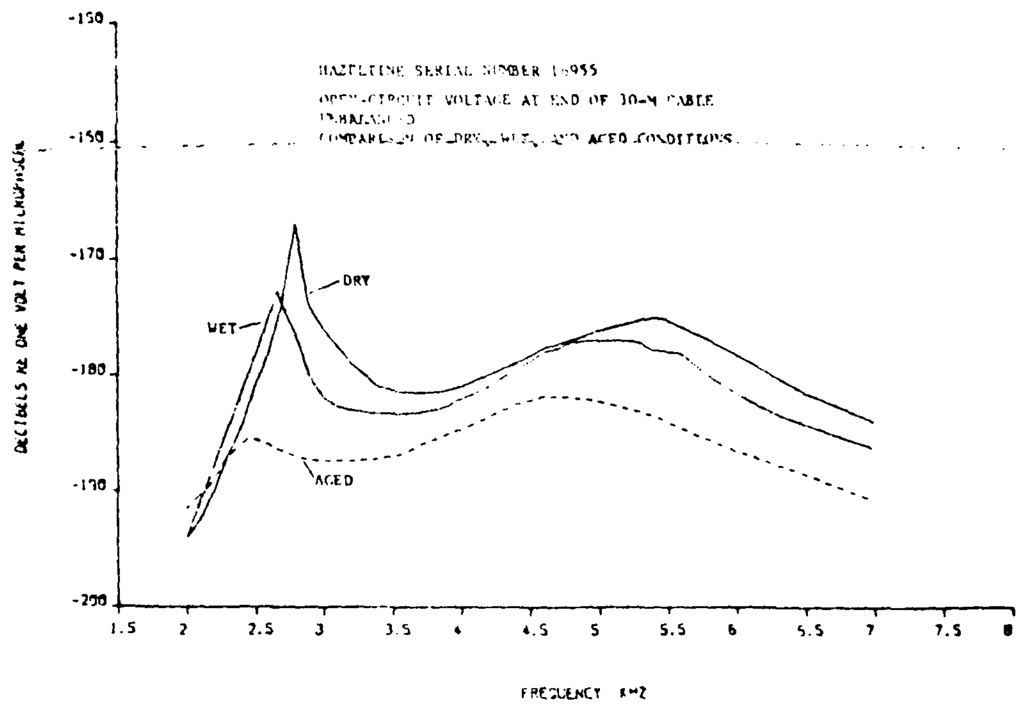

Fig. 11.1 - Free-field voltage sensitivity TR-208

11.3.2. Permeation Studies

Two separate permeation experiments with virtually identical parameters have been performed at TRI. The first experiment began on 10 September 1980 and the second began on 5 January 1981. Both experiments were designed to investigate permeation behavior of deionized water and 3.5% by weight sodium chloride solution through Neoprene-G. The permeation cells expose 24.86 cm^2 of

neoprene to the permeant, and all neoprene membranes are 2.54-mm thick. The cells are kept in a 60°C oven except during the weighing procedure at which time they are allowed to equilibrate to room temperature for 30 minutes.

Permeation Experiment No. 1 - This experiment has been in progress for about 285 days and is exhibiting heretofore unseen behavior. Looking at Fig. 11.2 one can see three distinct slopes on the fresh water curve whereas the salt water line is straight for the entire time. The first increase in permeation rate for fresh water was noticed after 100 days; so far that increase has been the most profound, changing from 1.69 mg/cm^2/day to 2.08 mg/cm^2/day, a factor of 1.23

The experiment was continued with data points taken usually once a week. Very recently, when the current data were plotted, this unusual behavior was seen again. At 191 days into the experiment the rate changed from 2.08 mg/cm^2/day to 2.35 mg/cm^2/day, a factor of 1.13 increase. Explanation for this phenomenon is awaiting an analysis of both the permeant and the neoprene. This may be a very important and new discovery which relates to transducer technology.

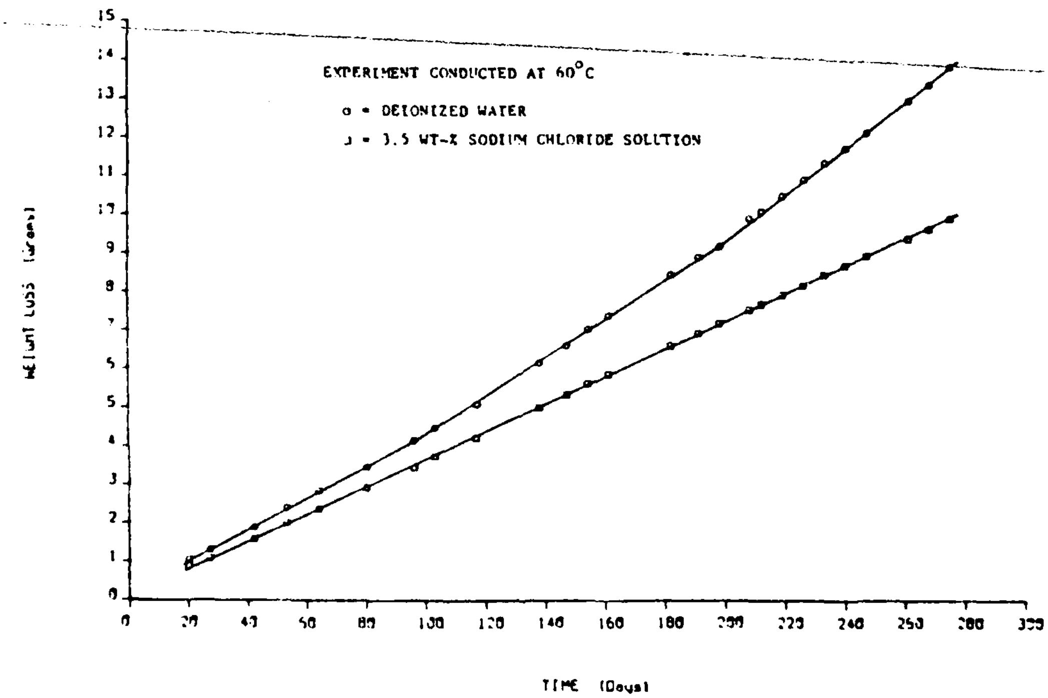

Fig. 11.2 - Permeation through Neoprene-G
(Experiment #1)

Permeation Experiment No. 2 - A second set of permeation cells was used to duplicate the first experiment. The cells and membranes were of the same dimensions as those in the first experiment, and they were kept in the same 60°C oven. When the phenomenon of the increasing permeation rate was discovered in the first experiment, the second experiment became even more

significant since it could possibly reproduce this behavior for verification. At approximately 81 days into the second experiment, the permeation rate for the cell with deionized water increased from 1.51 to 1.63 mg/cm^2/day, a factor of 1.08. This occurred before the second change in the first experiment. The permeation of sodium chloride solution reaches steady state very early and remains at that rate, at least for the duration of these experiments.

11.3.3. Temperature Profiles of X-308 Transducers

A knowledge of the temperature profile within a transducer is necessary to know where water vapor might condense during cooling or from where water may evaporate during heating cycles. Two X-308 transducers were each fitted with 12 iron-constantan thermocouples (Tc) at internal sites along the length of the element. One of the elements, No. 2, was flushed with dry air and sealed. The other, No. 4, was filled with castor oil that had been dried (<0.1% moisture) with Type 4A molecular sieves. Two types of experiments were performed with the Tc fitted transducers: (1) internal versus ambient temperature changes, and (2) internal heating and cooling rates of the transducers under active drive conditions.

Internal Versus Ambient Temperature - Both the air-filled and castor oil-filled elements were placed in a tank of salt water (sp. gr. 1.022 at 24°C). The Tc bundle from both units was connected to a 24-pair Tc cable which was connected to a 24-channel temperature recorder. The temperature of the bath was taken to 28°C, slightly above ambient, for the start of the experiment. The tank water was then cooled by pumping a solution of methanol/water (sp. gr. 0.938, f.p. -35°C) through heat exchanger coils inside the tank and also inside a heat exchanger bath located adjacent to the tank. The bath contained ice and 20 wt-% sodium chloride solution (f.p. -16°C). Cooling rates during the experiment varied from 2.5 to 7°C per hour. Approximately four hours into the experiment (at about 10°C) the cooling rate had slowed to the point where ice was added directly to the hydrophone tank to bring the temperature down to the desired level of zero or less.

A new experiment was performed in an effort to provide more useful data. The Tc's in elements nos. 2 and 4 were connected to the recorder and the elements were plunged into ice water (-16°C). The recorder was set to record a Tc temperature every two seconds. Internal versus external temperatures follow quite closely with no significant deviations.

Heating and Cooling Rates of X-308 Transducers Under Active Drive Conditions - Various sites within X-308's were monitored when the elements were driven with a power source. Also monitored was the rate of cooling after the power was turned off and the elements submerged in water at ambient temperature. Power was supplied to these units by a Model ENI 240L RF power amplifier. The power input for element no. 4 began at 17 W; it was increased to 20 W at 1.5 hours, and ultimately 48 W at 3.3 hours into the test. The air-filled unit began at 25 W, and the power was increased to 30 W at 1.0 hour, 36 W at 2.0 hours, and 45 W at 2.5 hours.

In general, the maximum temperature allowed was about 60°C, reached in 5½ hours. The headmass reached the highest temperature (57-60°C) and the heat

sink was lowest (46-48°C) of all parts. Upon cooling (30 minutes) all locations retained their respective positions on the cooling curves.

11.3.4. Accelerated Aging of X-308 Transducers

Two X-308 transducers were dried, and one was filled with air (element no. 1) and the other with dry castor oil (element no. 3). Characterization tests for impedance versus frequency and phase angle versus frequency were run on both units in the dry condition. Both elements were then injected with a calculated amount of water to give an internal relative humidity of 89%. The transducers were then immersed in a tank of salt water at 70°C to begin accelerated aging. Characterization tests will be conducted on a weekly basis to determine effects of aging. After one week in the aging tank both types of data have begun to show a noticeable change.

11.3.5. Evaluation of Water Ingression and Desiccant Effectiveness

An analysis of water ingression for an X-308 transducer was performed using a permeability constant of 2.16×10^{-8} g-cm/cm^2-hr-torr (for neoprene), 576 cm^2 window surface area, 0.32 cm window thickness, and an initial ingression rate of 16 mg/day. The saturated capacity of a castor oil-filled unit is 19 g of water and of an air-filled device is 38.5 mg at 20°C. These values disregard adsorbed moisture which may be significant.

The rate of water ingression is very high on this model, much higher than on previously calculated systems. Air saturation would be reached rapidly; but the RH increase in a castor oil fill-fluid would take much longer, due to the fact that the water capacity of castor oil is nearly 500 times greater than that of air.

A desiccant such as molecular sieves, which is useful in drying castor oil, would be effective and helpful in a castor oil fill-fluid and necessary in an air-filled void. The capacity of 100 g of Type 4A molecular sieves is 23.5 g. This capacity is the equivalent of nearly four years of water ingression at the maximum (initial) rate.

If the model transducer is used in the passive mode, internal temperatures track ambient temperatures, which makes location of the desiccant package inconsequential. However, in the driven mode, the placement of the desiccant needs to be away from the heat source and near the heat sink (case). The internal humidity will not be known under accelerated aging conditions (70°C) even though a high humidity (89%) will be supplied at the start of the test at 20°C. This is because of the following factors which are affected by temperature changes and the composite effect is unknown:

- Solubility of water in castor oil.
- Vapor pressure of water.
- Internal surface adsorption/desorption of water.

Another problem was averted by applying a layer of aluminum foil between the window and fill-fluid. This was done to prevent moisture from dissolving in or permeating through (either in or out) the rubber window.

11.4. PLANS

The two TR-208A transducers used for electronic characterization studies will be dried and returned to NRL-USRD for the final series of tests. Neoprene permeation samples will be analyzed for surface compositions and the permeant will be analyzed for compositional changes that occurred during the experiments. ALT testing will continue for two units. In-depth data interpretation will be addressed.

12. TASK F-2 - ENGINEERING ANALYSIS: CERAMIC STACK JOINTS

[illegible] and *C.T. Bolman - NOSC*

12.1. BACKGROUND

A severe deterioration in the electroacoustic performance of piezoelectric ceramic stacks that are assembled with epoxy adhesives has been observed at elevated temperatures that are due to either the environment or self-heating. Initial investigation has indicated that this degradation can be attributed partly, if not wholly, to a softening of the cement holding the ceramic stack together when high temperatures are encountered.

12.2. OBJECTIVES

The objectives are to identify and quantify the temperature dependent parameters of cements and ceramic that are used in transducer fabrications, to develop optimum cement joint configurations and fabrication techniques, and to develop math models of cement layers for use in transducer element design that account for the configuration of the cement joints as well as the temperature dependence of the cement.

12.3. PROGRESS

A computer model of a piezoelectric ceramic stack resonator, including cement joints, has been exercised in a parameter variation study. Figure 12.1 shows some of the results of this study. For the ceramic, the dielectric constant (ε_{33}), compliance (s_{33}), and piezoelectric constant (g_{33}), were varied in their real and loss related (multiplier) parts. For the cement/electrode joint, the sound velocity (C_c) was similarly varied. In each plot the varied parameter is specified. For example, in the bottom left plot the real part of C_c (CR) is varied from 1500 to 3500 m/sec (all units are MKS) and in the bottom right plot the "multiplier" of C_c (CM) is varied from 0 to 0.08 (CM is the negative of the imaginary part of C_c divided by the real part of C_c). In each plot all parameters, other than the one being varied, are set to "normal" values. The ceramic "normal" values were taken from a ceramic manufacturers published specifications for type 4 ceramic (PZT-4). In the interest of space, all of the plots in Fig. 12.1 are reductions of originals. The resulting lack of legend legibility has been hopefully solved by the arrows shown on the various plots. The important changes in the curves resulting from the parameter variations are always monotonic. Thus, the arrows show the direction of the changes in the key features of the curves as the parameter being varied increases. Two observations which are apparent are: (1) the anti-resonance frequency (f_n) and its impedance magnitude are almost entirely dependent on the mechanical parameters, i.e., s_{33} and C_c, and (2) all of the multipliers (loss factors) chiefly effect the impedance magnitudes at resonance (f_m) and anti-resonance (f_n) and have hardly any effect on f_m or f_n themselves. One other item is of interest here - if it is assumed that the actual cement sound velocity, CR, decreases with temperature and that the cement loss factor (CM) increases with temperature then the combined behaviors shown in the two cement parameter variations would yield results very similar to early experimental results of the effects of increasing temperature on in-air, unloaded acoustic resonators of the type modeled in this study.[5] Of course, the full usefulness of this type of model study will come when the ceramic and cement/electrode joint temperature dependencies are obtained.

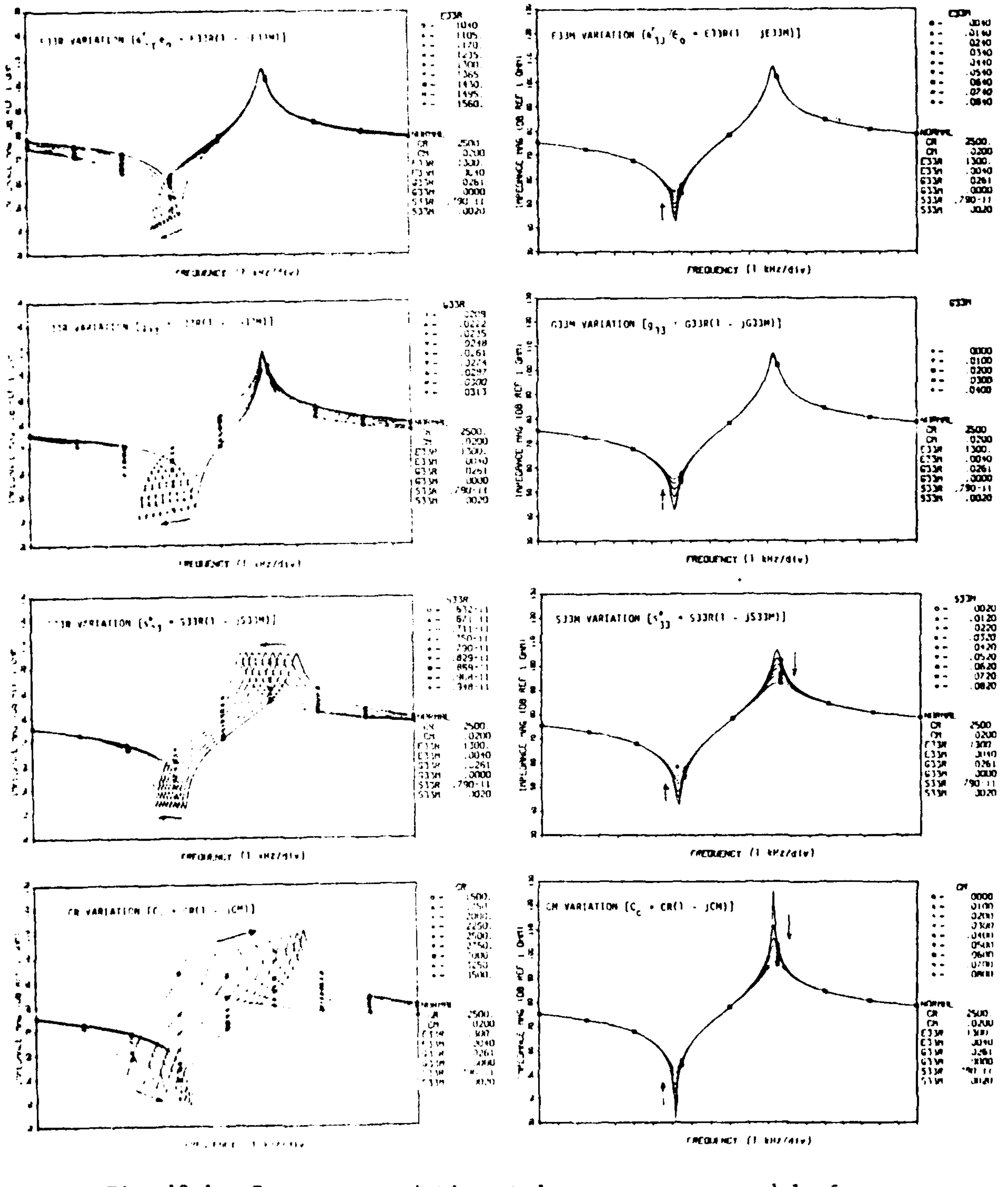

Fig. 12.1 - Parameter variation study on a computer model of a 33-mode peizoelectric ceramic stack resonator.

An infrared (IR) temperature measurement system has been developed in order to obtain surface temperature profiles of operating dumiloaded acoustical resonators. One purpose of these measurements is to provide direct insight into thermal characteristics of the resonator which may effect its operation. Another purpose is to provide temperature distribution information so that temperature dependent values for the ceramic and cement/electrode joint parameters can be specified for use in the resonator computer model. The IR measurement setup is shown in Fig. 12.2. The system features a non-contact infrared thermometer mounted on a linear translation stage driven by a stepping motor. The IR sensor has a 0.05-in. diameter target spot size at a focus distance of 1 in. A system controller directs the positioning of the IR sensor and handles the data acquisition, storage, and presentation. The position reference is a physically small, heated resistor which sits at a fixed, known distance from the test resonator. Once the IR sensor locates the position reference, it moves to the tail edge of the resonator. Then the temperature profile of the resonator is obtained by taking measurements at fixed increments along the resonator.

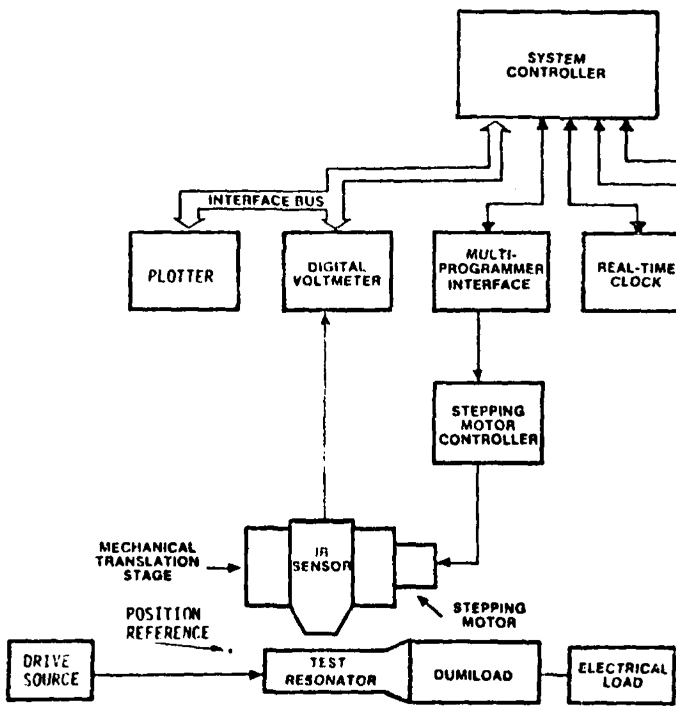

Fig. 12.2 - Infrared temperature measurement system

TI-ME

Some initial IR temperature measurements were made for an unloaded stacked piezoelectric ceramic resonator, while the resonator was being driven in air at 10 and 15 V (rms). The measurements were taken only after the resonator drive had been on long enough to allow steady-state thermal conditions to be reached. Results from two separate measurements are shown in Fig. 12.3. The dots represent the individual data measurements. A one dimensional representation of the resonator is at the bottom of the plot, scaled appropriately to the abscissa. These plots assume a uniform emissivity of unity along the resonator. Thus, the temperatures shown are not absolute and, in addition, temperature comparisons are not valid between sections of the resonator which contain differing materials. (Absolute temperature measurements along the entire length of the resonator will be obtained in the near future when reliable emissivity measurements along the resonator are in hand.) In Fig. 12.3, examination of the temperature distribution in the ceramic sections appears to indicate that the nodal ring, head, and tail act as heat dissipators since the temperature in the ceramic appears to decrease as these sections are approached. There is no clear indication here of a large amount of heat generation in the cement joints for an in-air, unloaded resonator, driven at 10 or 15 V (rms).

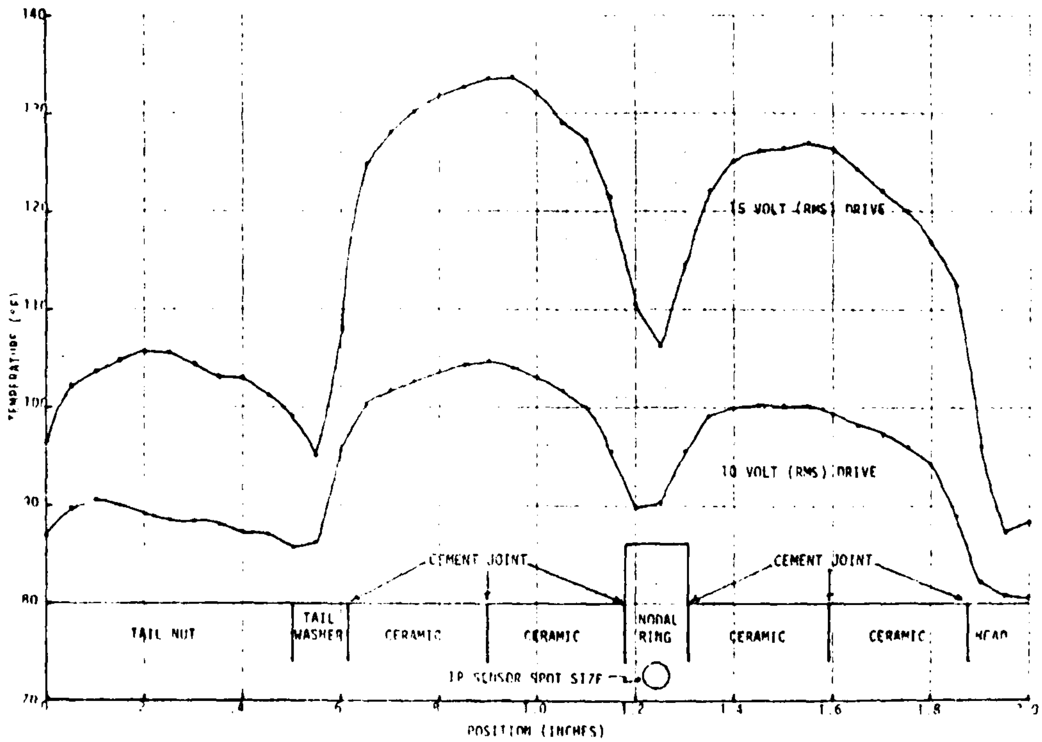

Fig. 12.3 - Longitudinal, infrared temperature profiles of an unloaded piezoelectric ceramic stack resonator, in air, with the emissivity taken to be unity along the entire resonator.

A dumiload has been constructed and tested for a specific piezoelectric ceramic stack resonator. The dumiload approximates the type of loading that the resonator would see in normal operation. Initial results indicate that the dumiload functions properly. IR temperature measurements should be obtained in the near future for a dumiloaded resonator under high drive.

Work relative to ceramic and cement joint measurements is being carried out under another task by Dr. G. Martin (SEI). The work has bearing on the STRIP cement joint effort as follows. Recent analysis using a finite element computer program indicates that ceramic parameters for the 33-mode may be measured with good accuracy using the thickness mode of a disc. The measurement of cement joint parameters is being approached by examining the resonance of long steel rods cemented together with or without a pair of ceramic discs included. Initial measurements should be obtained in the near future for both ceramic and cement/electrode joints. The measurements of these parameters as a function of temperature will provide necessary temperature dependent inputs for the resonator computer model.

Under another separate task, development of an interferometric test facility has begun which will possibly enable measurements of ceramic parameters as a function of temperature in FY82. This follows the investigation of ceramic parameter measurement techniques developed by Dr. P. Chen of Sandia Laboratories.

12.4. PLANS

Reliable emissivity measurements of the test resonator will be pursued to obtain absolute IR temperature measurements along the entire length of the resonator. Also, temperature profiles will be obtained for a dumiloaded resonator under high drive.

In conjunction with a separate task, the development of ceramic and cement joint measurement methods will continue, striving toward the capability to measure parameters as a function of temperature.

In the second quarter progress report, plans were made to test a variety of cement/electrode joint configurations. However, since then, such an effort has been deemed of secondary priority and will not be pursued until FY82.

Write an interim report covering the progress of the cement joint investigation to date.

13. TASK F-3 - RELIABILITY [illegible] PREDICTION SPECIFICATION

R.L. Smith and [illegible] - Texas Research Institute, Inc.

13.1. BACKGROUND

The reliability and [illegible] requirements for wet end sonar equipment need to be better defined. Present [illegible] style reliability prediction methods do not account for redundancy [illegible] there seems to be no unified approach to carrying out a prediction [illegible] life in the sonar context. Even to speak of reliability and [illegible] independent concepts ignores their formal duality in reliability theory. [illegible] improvements in reliability and life definition and prediction [illegible] needed for STRIP objectives to be met. For example, specifying MTBF does not uniquely determine the reliability in the time frame of particular interest [illegible] first few years of service. Other factors, such as the definition of failure, and the use of redundancy in the design dominate the reliability versus time relationships. Specifying service life in years does not embrace degradation during storage nor does it uniquely define wearout reliability.

Reliability is a very [illegible] statistical concept based on the behavior of a group of nominally identical items. Reliability itself is a distributed quantity, i.e., best represented by a normalized distribution or probability density function. The parameters appearing in reliability models are also distributed. Inferences relating to all such quantities are based on limited sets of observations which yield only estimates of the parameters of interest. However, the methods of statistical inference allow us to make the most definitive statements possible under the circumstances.

The present approach used by the Navy for wet end sonar equipment procurements is to specify numerical reliability and life requirements in the Critical Item Procurement Specification (CIPS) and to ask the contractor to achieve these objectives through a reliability program described in attachment 2 to the contract. Unfortunately, for the reasons given above, a contractor can fulfill all the requirements as currently stated and still deliver hardware that performs less than satisfactorily.

13.2. OBJECTIVES

There are two major [illegible] sonar reliability objectives:

- Provide the analytical basis for improved hardware reliability.
- Facilitate hardware improvement by developing more satisfactory procurement specifications.

Intermediate task objectives in support of the above are:

- Task 1 involves extending the Failure Modes and Effects Analysis (FMEA) approach to cataloging hardware vulnerabilities to provide type identification of wearout and random hazard modes.

- Task 2 is a reliability modeling study of four different degradation processes--water permeation, bond-line degradation, fatigue, and corrosion. This will involve combining kinetic process descriptions with probabilistic design reliability ideas to synthesize time-to-failure distributions.

- Task 3 involves examining the effect of data input uncertainties on the conclusions developed in a standard handbook style (exponential model) reliability prediction exercise. The DT-513A preamplifier will be used as a specific hardware focus.

- Task 4 uses the methods developed in previous tasks to perform a combined random hazard and wearout evaluation of the DT-276 hydrophone.

- Task 5 is an exploratory study to evaluate the applicability of the methods of Bayesian inference in the sonar hardware setting.

- Task 6 is a documentation task involving assembling the information developed in the other program phases into a format useful to the transducer community. Topics to be included are reliability and life prediction methods, mission profiles, use of subjective informational inputs, failure modes and effects analysis, and reliability specification.

- Under Task 7 a revision of attachment 2, the Transducer Reliability Program, will be prepared. This will emphasize failure mechanisms analysis, wearout reliability, redundancy implications, and relevant historical inputs.

13.3. PROGRESS

The need for military equipment of high reliability is fairly obvious both in terms of meeting mission objectives and from a cost effectiveness standpoint. This situation has long been recognized, of course, and a heroic infrastructure developed to deal with it. In the military procurement setting one small slice of conventional wisdom - the exponential model - has been extracted for use from a large and diversified body of information. This choice was not injudicious but is confining. The exponential model, although only one of many alternatives, is probably the reliability description of most fundamental importance for two reasons:

- The exponential model correctly describes the length-of-life behavior of components whose resistance to loss of function in service or under load (strength in a generalized sense) is not time dependent, provided the same operating environment (statistical stress distribution) is experienced throughout the use period.

* Complex systems tend to be exponentially reliable even if their components are not themselves individually exponential.

The exponential reliability description is also referred to as the random hazard model because the hazard function or per unit time probability of failure is constant in time. This has some interesting implications. For example, the probability of successfully completing a mission is independent of the age of the item involved. Also preventive maintenance has no meaning. A component remains as good as new until some overstress abruptly alters its condition to a failed state. There are many products such as electronics components, glassware, and pottery for which this is a reasonable description. In contrast many basic materials, rubber, steel, chemicals, etc., degrade during storage, environmental exposure, and use resulting in a time dependent reliability description termed wearout. Systems assembled from components drawn from either category can exhibit an overall exponential reliability behavior. In such a case the underlying randomness is a result of structural heterogeneity or perhaps repair strategy rather than stationary properties. The exponential model could just as well be called the maximum ignorance model because all process dynamics information and all associations of cause and effect are suppressed. One ignores the details of their origins and asks only on the average how often failures occur.

In the military procurement setting, exponential modeling in the form of either the Part Stress Analysis or Parts Count methods (per MIL-HDBK-217C) is the nearly universal reliability description tool. Part Stress Analysis recognizes that the parameter of the exponential model, although time independent, does depend strongly on a variety of loading or stress, quality, and use conditions. Even at this level of sophistication an important feature is missing. No measure of the precision of the output or dispersion estimate is provided by the handbook reliability method. Reliability is the probability that an item will perform successfully under stated conditions. As such, it cannot be directly measured for a single component but must be inferred from the behavior of a population of similar devices that have seen similar service. Even if the components tested are truly identical (a pedagogical idealization), the determination of the parameter of the parent population is limited by the statistics of sampling. One would like to see handbook entries qualified on this basis but they are not. Since the similar items tested are in fact not identical, further refinement calls for incorporating this overall properties dispersion into the modeling description. The "constant" parameter of the exponential model becomes more properly a distributed random variable.

In this project and in this report, the exponential model is assumed to be appropriate. The reader is cautioned that in dealing with a specific hardware problem in practice the validity of using exponential modeling must be separately tested.

Work on the Failure Modes and Effects Analysis approach to addressing sonar reliability issues have been initiated during this reporting period. However, the major emphasis has been placed on developing a description of the dispersion aspects of exponential modeling. The major features of this issue are identifying the uncertainties associated with the supporting data, combining these uncertainties appropriately via error propagation analysis,

and recognizing and dealing with the true dispersion of serviceability properties that complicate the problem. Exponential modeling requires as an input that the failure rates of all components of a system be specified. There is no way to obtain this information except via measurement, whether it be direct observation of times to failure or synthesis of component modeling parameters via stress/strength overlap calculations. The latter are based on systematic specification of the distributions of stress that characterize transportation, storage, and use and a similar probabilistic description of component strength.

To understand how the necessary failure rate information is developed, consider the following classical problem in sampling statistics. Imagine that a population of n identical, exponentially reliable devices are being tested and the times t_i at which failures occur are being recorded. For this situation the hazard rate, time-to-failure distribution, and the reliability are respectively $\lambda(t) = \lambda$ (a constant), $f(t) = \lambda e^{-\lambda t}$, and $R(t) = e^{-\lambda t}$. It is common to express these relationships in terms of the mean time to failure $\theta = 1/\lambda$. Thus either θ or λ may be referred to as the parameter of the exponential distribution. To make the example more specific, we treat the case where failed units within the test population are not replaced and testing is suspended when the r^{th} failure occurs; i.e., a failure terminated, non-replacement test. Testing yields directly the failure times t_i; our interest, however, is in the parameter θ (or λ). How does one infer the model parameter from time-to-failure data? A preferred approach is maximum likelihood function L is a measure of the probability of occurrence of the actual experimental outcome expressed in terms of the modeling parameter. It is given by the product of the probabilities that failures should occur at the observed times t_i and that n-r units should be unfailed at the test termination time t_r. Thus

$$L = \left[n\lambda e^{-\lambda t_1}\right]\left[(n-1)\lambda e^{-\lambda t_2}\right] \cdots \left[(n-r+1)\lambda e^{-\lambda t_r}\right]\left[e^{-\lambda t_r}\right]^{(n-r)} \qquad (13.1)$$

Or collecting factors

$$L = \frac{n!\,\lambda^r}{(n-r)!} \exp\left[-\lambda\left(\sum_{i=1}^{r} t_i + (n-r)t_r\right)\right] \qquad (13.2)$$

All parameters of L are known except the hazard rate λ which is regarded as an unknown constant. Maximum likelihood theory adopts the position that we can imagine varying λ until the likelihood function takes its largest possible value. This yields a value of λ or more commonly θ for which the collection of actually observed failure times t_i is more probable than for any other choice of the exponential modeling parameter. Explicitly this so called maximum likelihood estimator $\hat{\theta}$ of the true distribution parameter θ is given by

$$\hat{\theta} = \frac{1}{r}\left[\sum_{i=1}^{r} t_i + (n-r)t_r\right] \qquad (13.3)$$

If now we choose to repeat the reliability measurement just described, even with truly identical test units, a new and different set of failure times will be recorded. A second and different maximum likelihood estimator will result as well. Further repetitions of the test will yield a full distribution of outcomes. In this case the true modeling parameter θ is correctly given as the mean or expected value of the distribution of $\hat{\theta}$. Usually, however, we cannot afford multiple reliability tests. The problem of interest becomes to infer a necessarily distributed description of θ from a single observation of $\hat{\theta}$. This proceeds as follows: Epstein and Sobel[6] have shown for the case being considered here that the quantity $z = 2r\hat{\theta}/\theta$ is χ^2 distributed with 2r degrees of freedom. This is

$$f(z) = \frac{1}{2^r(r-1)!} z^{(r-1)} e^{-z/2} \tag{13.4}$$

Via standard distributed random variable transformation methods one can state the distribution of $\hat{\theta}$ (in terms of constants r and θ) as

$$f(\hat{\theta}) = \left(1/(r-1)!\hat{\theta}\right)\left(r\hat{\theta}/\theta\right)^r \exp(-r\hat{\theta}/\theta) \tag{13.5}$$

Confidence limits are developed on $\hat{\theta}$ at the $1-\alpha$ confidence level in the usual way via the probability statement

$$P\left[\chi^2_{(1-\alpha/2),2r} \leq \frac{2r\hat{\theta}}{\theta} \leq \chi^2_{\alpha/2,2r}\right] = 1-\alpha \tag{13.6}$$

However, the real concern is a dispersion description on θ or λ not $\hat{\theta}$. Thus Eq. (13.6) may be inverted to read

$$(1/2r\hat{\theta})\chi^2_{(1-\alpha/2),2r} \leq \lambda \leq (1/2r\hat{\theta})\chi^2_{\alpha/2,2r} \tag{13.7}$$

Equation (13.7) is assailed as being the result of incorrect logic.[7] That is, Eq. (13.7) follows from Eq. (13.6) only if λ is itself a random variable and not a constant as has been assumed. Arguments will be presented elsewhere[8] that it does make sense to describe our knowledge of the modeling parameter λ in distributional terms. This follows from viewing a specific reliability measurement as if it were drawn from an ensemble of related evaluations (differing only in λ) all leading to the same MTBF estimator value $\hat{\theta}$. Thus regarding $\hat{\theta}$ as a constant now taking its single observed value and our knowledge of λ as distributed, Eq. (13.7) is correct and Eq. (13.4) implies the distribution on λ

$$f(\lambda) = \left(1/(r-1)!\lambda\right)\left(r\hat{\theta}\lambda\right)^{r} \exp(-r\hat{\theta}\lambda) \qquad (13.8)$$

This description should be recognized as having a Bayesian flavor. Thus while we still maintain that the hazard rate λ is in fact an unknown constant in the exponential modeling situation, it is suggested that its value is best represented probabilistically, that is as a distributed random variable. The coefficient of variation of Eq. (13.8) and its analog in θ are respective $1/\sqrt{r}$ and $1/\sqrt{r-2}$. These are respectively the desired dispersion measures of λ or θ as a function of the number of failures r observed in a nonreplacement test of similar units. One sees from this, for example, that determining λ to a fractional precision (dispersion) of 10% requires observing 100 failures. Similarly, a 1% hazard rate determination calls for the testing of identical units under similar conditions until 10,000 failures have been cataloged.

Two generations of this basic approach have also been developed during this reporting period. These involve treating the observed failure times t_i as only approximately known, i.e., $t_i \longrightarrow t_i + \Delta t_i$. This is important in treating certain reliability tests of limited opportunity such as are commonly conducted on sonar systems in fleet service. Also in practice similar units are not actually identical. Thus, within a population, the modeling parameter θ or λ is not the same for all units but is distributed. This represents a real distribution of physical properties in contrast to the fuzziness of our knowledge of the situation (stochastic sampling) described above. Several examples of the impact of properties dispersion on exponential modeling have been worked up and will be presented in detail elsewhere and in subsequent STRIP reports.

13.4. PLANS

Immediate plans involve preparing a manuscript treating exponential modeling measurement and dispersion issues for submission to a reliability journal. The methods developed will then be applied to the DT-513A preamplifier as an illustrative example. Dispersion measures will have to be invented for this purpose since handbook modeling in its present state of refinement does not provide the necessary information directly. The overall thrust of this effort is to identify specifically the weaknesses of handbook methods and provide alternatives that allow more realistic descriptions of the random hazard class of reliability problem. Concurrently, the FMEA project task will be carried out and the other project tasks initiated.

14. TASK F-5 - FAILURE MODES ANALYSIS AND IMPROVEMENTS FOR TR-122

E.W. Thomas - NRL-USRD

14.1. BACKGROUND

The TR-122A/B (BQC-1) transducers are two-way communication devices installed aboard all US Navy submarines. In addition to the communication function, there is a built-in homing device for emergency use. This class of transducer was designed and built by the Dyna-Empire Corporation and has been in use on US submarines for many years. They are filled with a solution of dimethyl silicone oil, containing 83% Dow Corning 550 and 17% Dow Corning 200-10, that serves as an acoustic coupler between the seawater and the sensing elements of the transducer. One of the major disadvantages of using silicone oil is that the low surface tension causes it to creep continuously throughout the servicing area in the Transducer Repair Facilities of the Naval Shipyards. This insidious creepage results in a coating of a monomolecular-thick film of oil on all the exposed areas of the transducers, molds, cables, connectors, and associated hardware, which results in weak and unacceptable rubber molds and bonds, cement mixes, and elastomer fabrication.

Naval Sea Systems Command requested the STRIP program to determine the feasibility of replacing dimethyl silicone oil with Baker dB-grade castor oil as the fill-fluid on a class-by-class basis. One class of transducer has already been evaluated and recommended for filling with castor oil. Since the TR-122 transducer is the last class being processed through the Transducer Repair Facilities that is filled with dimethyl silicone oil, this investigation will terminate the silicone oil versus castor oil evaluation project.

14.2. OBJECTIVES

The objectives are to analyze the failure modes of the TR-122 (BQC-1) and to develop, test, and evaluate an improved replacement transducer.

14.3. PROGRESS

Previous study[6] suggests that substitution of Baker dB-grade castor oil for dimethyl silicone oil as the coupling fluid in the TR-122 transducer is not recommended. The study also indicates that in addition to the poor handling characteristics of the coupling fluid, that the operating characteristics of the transducer were borderline. The transducer has a poor record of meeting the published specifications.

An alternative transducer may exist in the form of the Model 55 transducer built for the Trident system by Dyna-Empire Corporation. This transducer appears to be superior in performance and reliability. Investigation at the factory and at the Transducer Repair Facilities lead to the conclusion that the internal components of the new transducer may be installed into a modified TR-122A/B case assembly and substituted into the existing fleet.

Sufficient internal components to assemble four TR-122X transducers were obtained. The modification of two TR-122X transducers was completed and tested at the Mare Island Tranducer Repair Facility. The photographs of the case modifications are currently being processed and will be shown in the next

report. The results of the acoustic tests on the transducers are shown in Figs. 15.1 through 15.4. The comparison of the actual curves to the curve predicted is very favorable. All values are well within the specifications for the TR-122 transducers. The transducers were subsequently shock-tested and preliminary post-shock tests indicate that they passed the shock test satisfactorily.

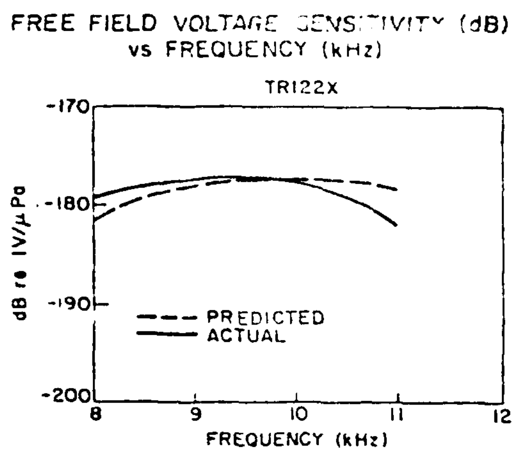

Fig. 14.1 - The actual curve is slightly better than predicted.

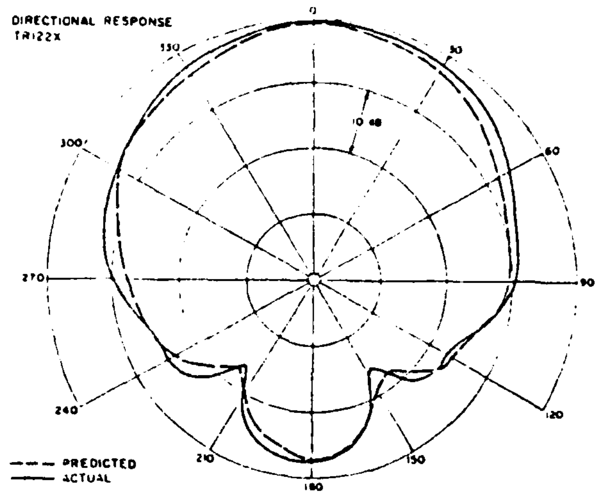

Fig. 14.2 - Directional response @ 9.6 kHz.

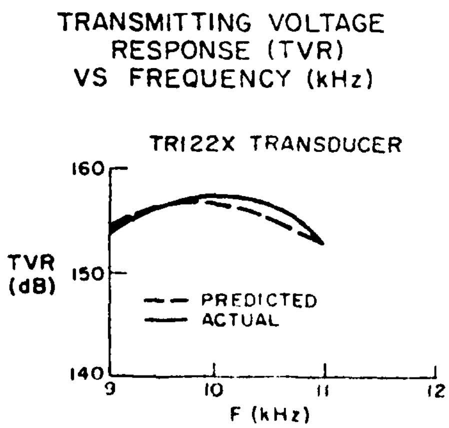

Fig. 14.3 - At the operating frequency of 9.6 kHz the actual curve meets expectations.

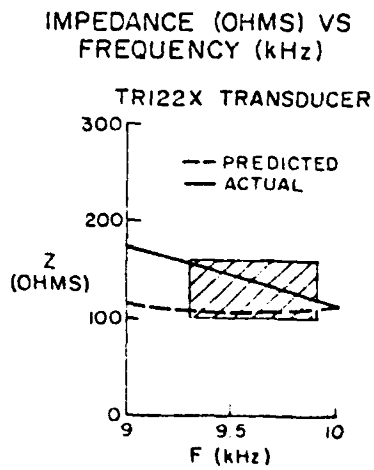

Fig. 14.4 - At the operating frequency of 9.6 kHz the actual curve is well within the specified limits which are cross-hatched.

14.4. PLANS

The two modified transducers will be acoustically evaluated post-shock in the Anechoic Tank Facility at NRL-USRD. The measurement parameters will include free-field voltage sensitivity, directional response patterns, transmitting voltage response, and impedance as a function of temperature and pressure.

Two additional transducers will be modified by Mare Island Transducer Repair Facility and will join the previous two in the accelerated life test designed to prove the TR-122X transducers for a life cycle of ten years.

15. TASK F-6 - IMPROVED HYDROPHONE ANALYSIS

M.P. Canty - NWSC

15.1. BACKGROUND

It has been found that the DT-276 hydrophone is not the perfect sensor to be used with BQQ-5 and BQR-7 sonar systems. If a hydrophone could be developed that meets all the system requirements of the BQQ-5 and BQR-7, eliminates the DT-276 shortcomings, and adds findings from STRIP, it will be the optimum replacement sensor for the DT-276.

15.2. OBJECTIVE

The objective is to provide the engineering analysis and development of an improved, more reliable hydrophone for use in sonar systems such as the BQQ-5 and BQR-7.

15.3. PROGRESS

With the elimination of the Integrated Sonar Processing Equipment Program, it appears the BQQ-5 and BQR-7 systems will be the primary passive sonars for the next 10 to 15 years. Tracor, Inc. has reviewed the existing front-end requirements for the BQQ-5 and BQR-7 and discovered that no immediate improvements in the DT-276 hydrophone will be required in frequency coverage or signal sensitivity. The limiting factors at this time are local noise, flow noise, number of staves, stave locations and arrangements and, in particular with the BQQ-5, the beam forming technique. As the sonar system's processing capability is improved it is anticipated a long-term improvement requirement will exist to increase input signal sensitivity. Even though no immediate improvements will be required in frequency coverage or signal sensitivity, areas to explore may include:

- Better directivity - gains would result in improved bearing resolution, more signal sensitivity and possibly decreasing local noise.

- Adding a local preamplifier to the hydrophone - this may reduce the signal line loss and with the higher signal level may reduce local noise picked up by the cabling.

- Redesigning the mount and/or hydrophone shape to reduce vibration and signal reflectivity.

Tracor, Inc. will continue to investigate design changes and/or performance requirements for the hydrophone. This task is to be completed during the fourth quarter of FY81.

Data from DT-276 hydrophones returned from the fleet are being analyzed to uncover problem areas. Failure analysis of 37 DT-276 hydrophones removed from the SSBN 617 showed three problem areas: low insulation resistance (IR) readings between black-to-white leads, low IR between the black lead and water, and low capacitance. Autopsy of units revealed that the low black-to-white

resistance was due to water entering the cable and migrating to the feed-thru sleeve in the hydrophone. Units with low black-to-water resistance had rubber boots that were not bonded to the ceramic cylinders. It is not known if water leaking into the hydrophones destroyed the bond or if the rubber was not bonded to the ceramics at time of manufacturing. Low capacitance was due to ceramic cylinders being cracked.

15.4. PLANS

- Continue with the engineering analysis of the requirements of the BQQ-5 and BQR-7 systems from the view of the transducer detection requirements.

- Compare CUALT on DT-276 hydrophones with a failure analysis of those returned from the fleet to uncover problem areas.

- Determine alternate design approaches such as

    - Integral versus in-board preamplifiers
    - Balanced versus unbalanced preamplifiers
    - Quick connect/disconnect versus a fixed cable
    - Butyl versus neoprene boots
    - A butyl, unshielded cable versus the present DSS-3 cable

  and other considerations such as improved back-baffling and even direct substitution of the DT-513 with modified mounting.

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